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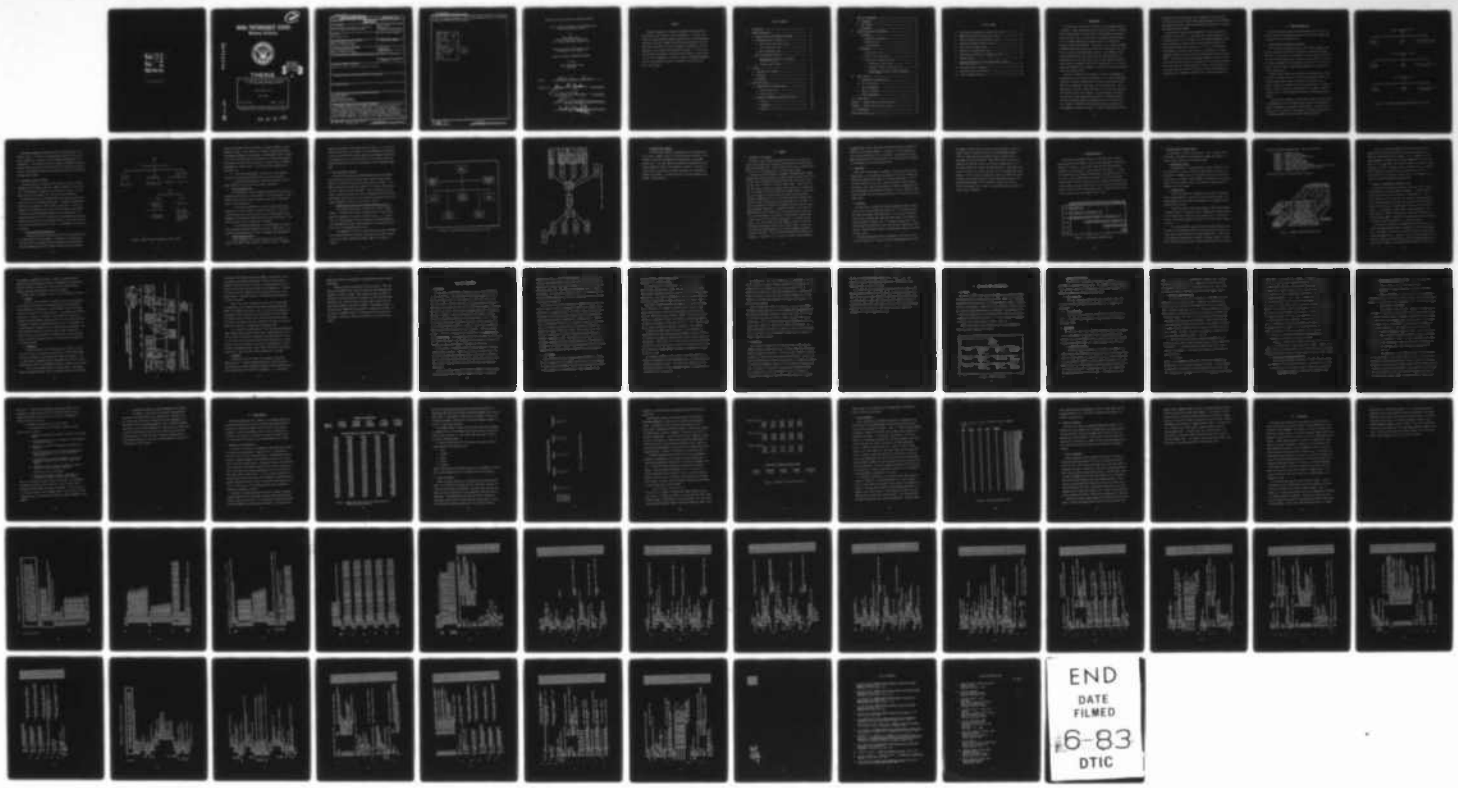

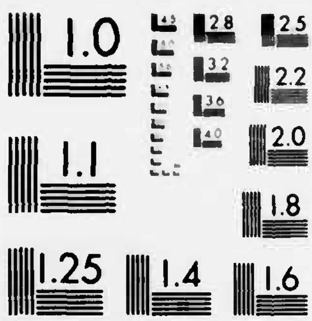
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NAVAL POSTGRADUATE SCHOOL
Monterey, California

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COST ESTIMATION AND PRODUCTIVITY IMPROVEMENT
WITHIN THE DEPOT MAINTENANCE ACTIVITY

by

Robert Dean Larson

March 1983

Thesis Advisor: James G. Taylor

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Cost Estimation and Productivity Improvement Within the Depot Maintenance Activity

by

Robert Dean Larson
Captain, United States Marine Corps
B.S., United States Naval Academy, 1974

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN OPERATIONS RESEARCH

from the

NAVAL POSTGRADUATE SCHOOL
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Equipment readiness is an essential component in maintaining the Marine Corps as this country's "Force in Readiness". In today's environment of austere funding, improved productivity and reliable budgeting processes are critical elements within the Depot Maintenance Activities. The optimal utilization of available resources is paramount to the enhancement of Fleet Marine Forces equipment readiness. This thesis uses the quantitative techniques of multiple linear regression, survey analysis and linear programming in an effort to model an automated management system for the maximum allocation of resources at the two existing Marine Corps depots.

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I. INTRODUCTION

The first duty of any military organization is the accomplishment of its mission. Today's peacetime mission for the Marine Corps is readiness with efficient resource utilization and reliable budgeting information serving critical roles. In the current environment of austere funding, it is of primary importance that budget planners be provided with accurate, up-to-date information. Accordingly, it is of equal importance to combine these dollars and the available labor workforce in their optimal mix to obtain the maximum output possible. The mathematical techniques needed to achieve this optimization are available within the academician's world, and can yield highly accurate results to questions that could only be answered previously by "best guesses." It is time to bridge the communication gap between the theoretical and practical worlds within the logistics field.

Historical information forms the basis of most of the mathematical techniques that are available and therefore it is of critical importance. Fortunately, logistics planners within the Marine Corps identified the need for the compilation and storage of this historical data. The reorganization of logistic support structures to allow for this collection and storage of data is well underway. The new structures incorporate the lessons of recent combat with the logistical techniques that are currently practiced by both the government and civilian industries today. Changes in organizational structure occurred in parallel with the changes in the logistics systems. As these systems evolved, planned

reorganizations were implemented, taking advantage of the new systems such as the Marine Corps Integrated Maintenance Management System (MIMMS), the Supported Activities Supply System (SASSY) and the Marine Corps Readiness Evaluation System (MARES).

Although these systems were not developed for the sole purpose of providing historical data, it is the time now to take advantage of this by-product and put it to its fullest use. An automated management system could be developed that would lead to greater system efficiency and effectiveness through better planning. All of this is available once our abundance of historical data is put to its maximum use. One such management system could be installed at the Depot Maintenance Activities (DMA). Quantitative forecasting can predict numbers of carcass returns and resource allocation models can outperform "seat of the pants" methods for the construction of the Master Work Schedule. Once the results are calculated, they can further be utilized to provide cost estimates for the operations of the DMA for submission to the Five Year Defense Plan.

II. CURRENT ORGANIZATION

The following organizational background information is given in an effort to identify the contextual setting for the problem statement that is contained in the following section.

A. GROUND EQUIPMENT MAINTENANCE ENVIRONMENT

The FMF has been undergoing a series of evolutionary changes in its logistic support structure and its supporting systems during the past five years. Much of this effort concentrated on corrections to deficiencies identified during the logistic rigor of the Vietnam War. Four areas of logistic management that have changed in the FMF are: the organizational structures, supply, maintenance management and the readiness reporting systems. [Ref. 1]

Organizational structures have undergone a change designed to shape the Tables of Organization (T/O's) more around the combat, combat support and combat service support structures as described in Ref. 2. Figure 1 outlines the common structures that have evolved. The consolidation of logistic support into modularized service support elements is characteristic of the reorganizational emphasis on equipment readiness support.

The organizational emphasis on the centralization of logistic effort is supported by the use of automated data systems for the processing of supply, maintenance and readiness evaluation data. The centralized logistic units of the FMF are more capable of coordinating these multiple information systems than were the decentralized structures.

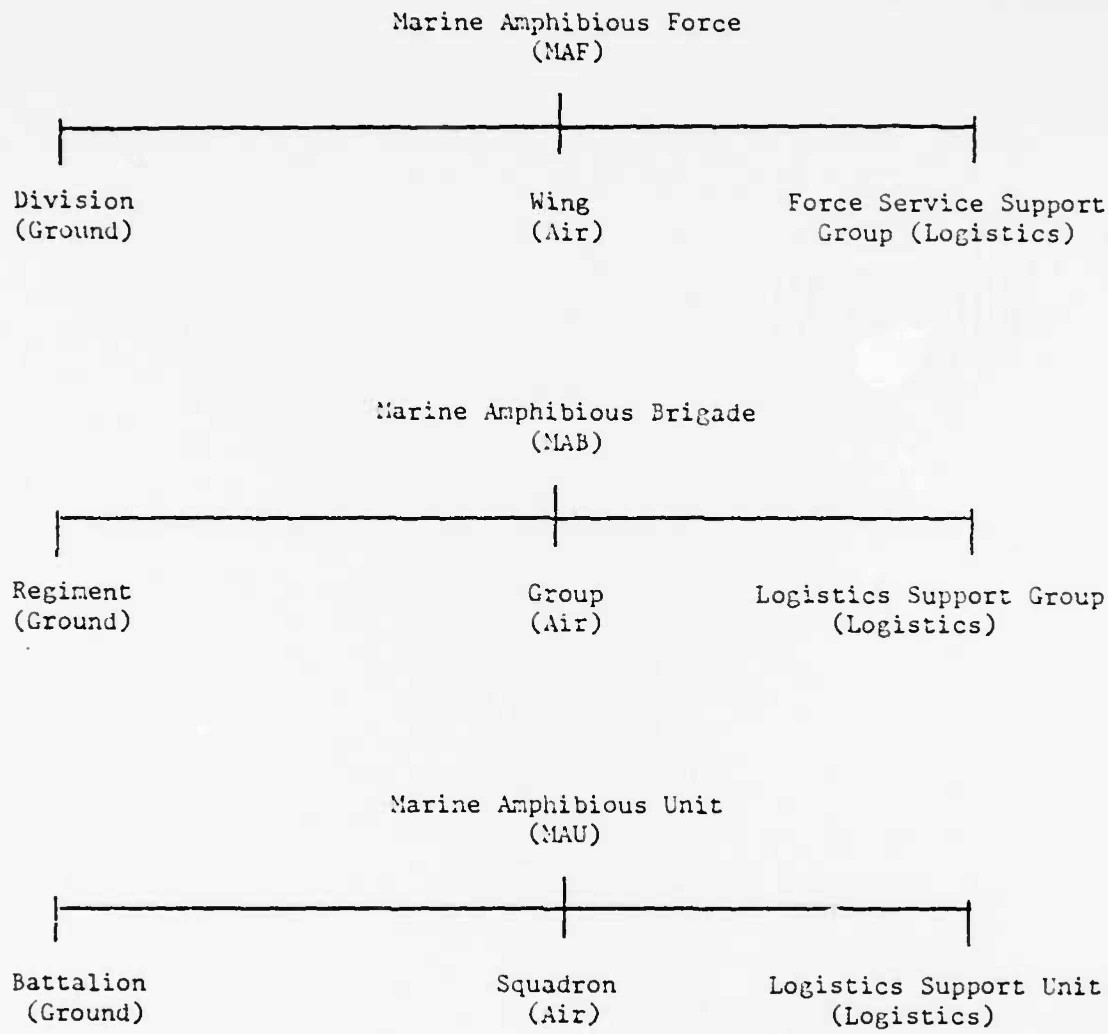

Figure 1. Three Basic Organizational Structures for the FMF

Maintenance management information has been centralized within the logistics units. The logistic units depicted in Figure 1 correlate and report information to using units, major commands and Headquarters level organizations. The information consists of supply, maintenance operations, equipment readiness and historical data relating to equipment maintenance. Figure 2 shows the MAF structure and relationships involved in maintenance management under MIMMS.

B. MAINTENANCE SUPPORT STRUCTURE

Maintenance consists of those actions required to retain or restore equipment to a serviceable condition. Commonly included in this description of maintenance are inspection, testing, servicing, repair, replacement, rebuilding, serviceability classifications and reclamation.

Maintenance services in the Marine Corps are governed by the logistic capabilities of the individual organizations. The Tables of Organization define for each organization their logistic capabilities. Three major categories of maintenance are divided into five echelons of maintenance to further define the maintenance capabilities of organizations. The echelons define the time, tools, equipment, parts and personnel available, authorized and required for a maintenance function. The official description of the maintenance structure in Ref. 3 is summarized in the following paragraphs.

1. Organizational Maintenance Level

Maintenance performed, authorized and within the responsibility of an organization on its own equipment is categorized as organizational. Two major types of maintenance actions performed at the organizational and field maintenance levels are preventive and corrective maintenance.

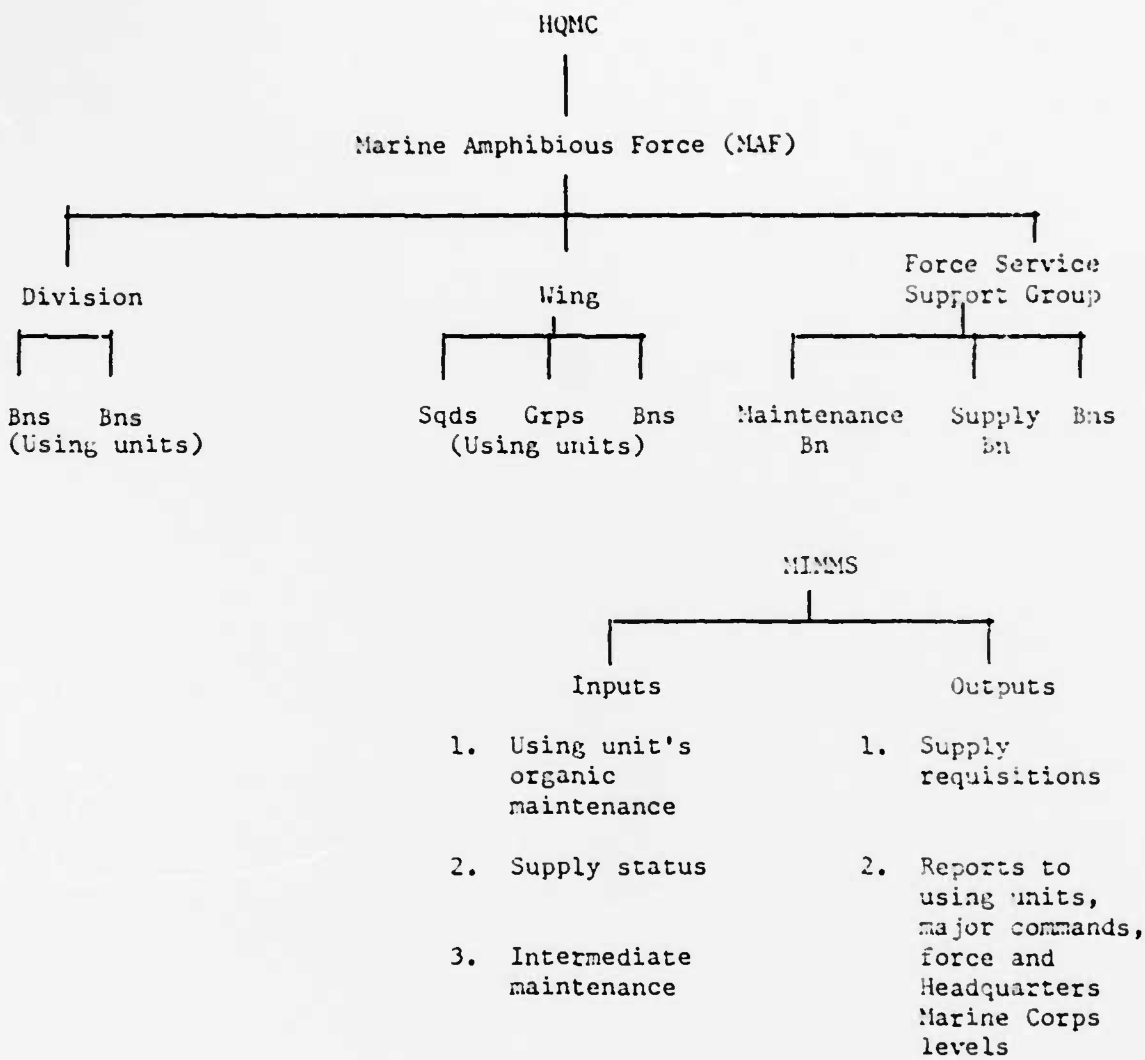

Figure 2. MIMMS Structure and Overview within an MAF

Preventive Maintenance (PM) is the effort to prevent or detect incipient equipment failures. Early detection is intended to reduce the downtime of equipment and improve its performance. Requirements for PM are focused at the first and second echelons of maintenance. Corrective Maintenance (CM) consists of those actions which repair, replace or adjust assemblies, subassemblies or defective parts. Two echelons within organizational maintenance are:

a. First Echelon Maintenance - preventive care and cleaning, lubrication and minor testing repair done by the user or operator.

b. Second Echelon Maintenance - actions performed by a trained member provided for that purpose in the using organization.

2. Field Maintenance Level

Field Maintenance is that performed and authorized by specifically designated organizations in direct support of using organizations. [Ref. 2] Repaired items from this level are returned to the user. Two echelons within field maintenance are:

a. Third Echelon Maintenance - actions performed by specially trained units in direct support to multiple using units. Select individual using units may, due to the peculiar and limited nature of some equipment, be authorized to perform their own third echelon repair. This echelon consists of part or module-type replacement.

b. Fourth Echelon Maintenance - actions performed by specially trained personnel beyond the supported using unit's capabilities. The functions performed provide for repair of assemblies and subassemblies.

3. Depot Maintenance Level

Depot maintenance is the fifth echelon and is the repair of materiel that requires major overhaul or rebuild. [Ref. 3] Equipment

repaired is returned to stock rather than to the user. It is within this level that this thesis will attempt to use the mathematical and statistical tools available to help provide the Marine Corps budget planner with the information crucial to making reliable cost estimations within the Depot Maintenance Activities for the upcoming and four subsequent budget years.

C. DEPOT MAINTENANCE STRUCTURE

The Marine Corps operates two Depot Maintenance Activities (DMA's). These activities are located at Marine Corps Logistics Base, Albany, Georgia and at Marine Corps Logistics Base, Barstow, California. The DMA's accomplish major repair and overhaul of all types of Marine Corps tactical, combat and support equipment. They are responsible for the timely collection and reporting of data to Headquarters Marine Corps and the Inventory Control Point (ICP) in the format and accuracy required to support management functions at those levels. [Ref. 4]

1. Organizational Structure of the Depot Maintenance Activity

The standard organizational structure for the DMA is shown in Figure 3. The DMA contains within its organization all essential elements for management of production, costs and quality. It is responsible for the development of detailed schedules and the development of local management techniques to ensure execution of the program requirements levied by Headquarters Marine Corps.

The Commandant of the Marine Corps Master Work Program (CMC MWP), the ICP Depot Repairable Program and the Supply Center Support Program constitute the annual Master Work Schedule (MWS) as illustrated in Figure 4.

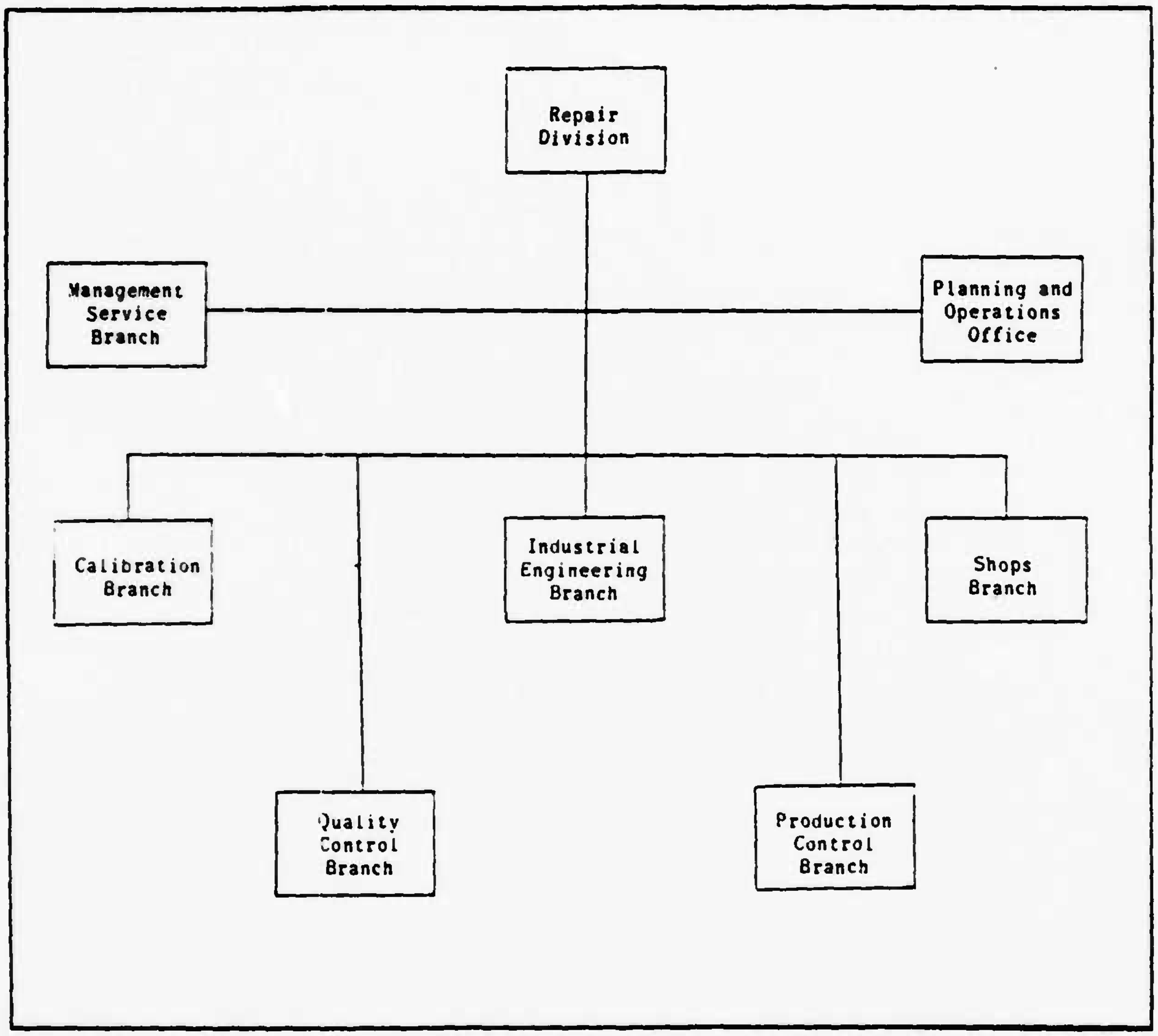

Figure 3. Standard Organizational Structure for a DMA

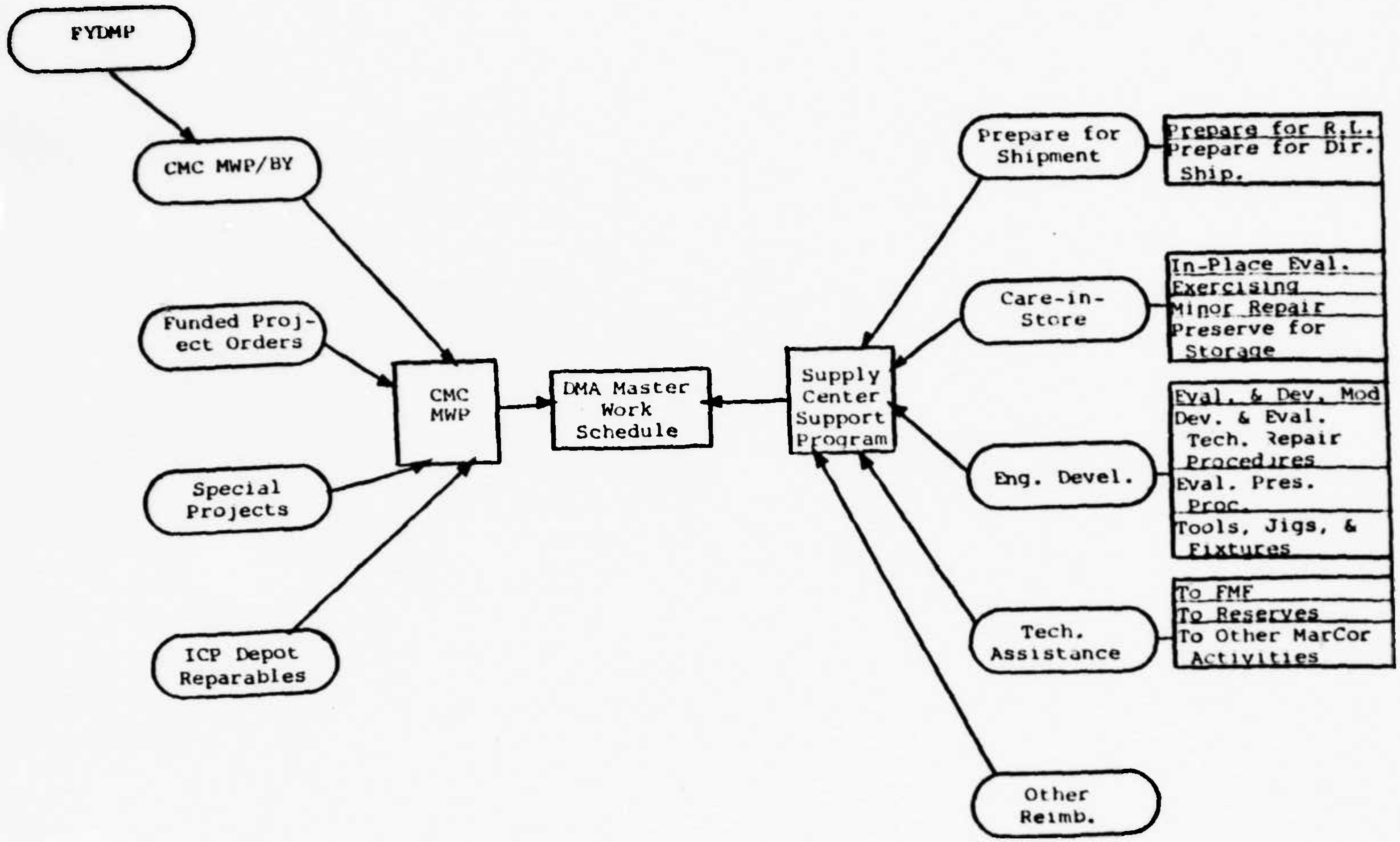

Figure 4. Master Work Schedule Preparation Chart

2. The Master Work Schedule

The Master Work Schedule is maintained in an up-to-date status at all times. Changes to the line item and quantities contained in the CMC MWP are received from Headquarters Marine Corps as requirement changes occur. Line item changes are estimated and scheduled by induction and completion dates as the changes are received. The status of allotted funds in relation to schedule requirements are maintained as changes are estimated. A formal submission of the revised Master Work Schedule is made quarterly.

III. PROBLEM

A. STATEMENT OF THE PROBLEM

Reference 4 tasks the Depot Maintenance Activities at Barstow and Albany with providing cost estimates for the Master Work Schedule within the Five Year Defense Plan. These estimates are utilized by Headquarters Marine Corps in the preparation of the apportionment budget.

Currently, the Interim Material Management Programming Model (IMMPM) and the Stratification subsystem are used to identify the total Principal End Item (PEI) and Secondary Depot Repairable (SDR) requirements which are then used as the basis for rebuild computations. These quantities are then priced out against an average cost to rebuild and a budget estimate is provided. The fallacy behind this thought process is the simple fact that planners are trying to use the output of the requirements computation (MMPM and Strat) as input to the Master Work Schedule when neither of these systems consider the output capacity of the DMA. Instead, the output of the Master Work Schedule should be used as input to the requirements computation. In addition, the model used within the IMMPM assumes unlimited funding and a continuous supply of carcass returns as do most models of this nature. Unfortunately, these assumptions are not valid for the Marine Corps due to its limited size and budget. It is quite obvious that the IMMPM was devised to calculate PEI and SDR requirements based on such things as usage, carcass return rate, depot level maintenance survival rates and budget constraints, and that it was then in turn forced upon the Master Work Schedule cost estimators. Once again, it is the story of trying to make automated

systems perform in areas they were not designed for and are incapable of handling. The problem statement is: Construct a set of programs that will yield the optimal mix of PEI's and SDR's to be repaired at the two Depot Maintenance Activities and calculate the associated cost estimation for the budget year and four subsequent years.

B. CONSTRAINTS

Due to the limited number of programmer assets available within the Marine Corps, it is believed that any methods identified to improve cost estimating techniques should meet the following requirements: First, the technology must exist and not create any unusual financial burdens on the user. Next, existing data bases and supporting programs must not be altered beyond simple modular replacement. Finally, changes to implement the methods must not increase the workload of the user or the initial input source.

C. METHODOLOGY

The Marine Corps Integrated Maintenance Management System currently tracks the life cycle maintenance records for all serialized Principal End Items and Secondary Depot Repairables. This historical data base can be used to calculate the regression coefficients for any number of factors relating to overhaul date. The regression equation will yield the approximate date when each serialized item would require depot level rebuild. These estimates can then be aggregated and sorted by end item and fiscal year.

Two look-up tables must then be constructed. The first will contain the different skill levels at each Depot Maintenance Activity and

the number of people within each level and the second will contain the times utilized in completing industrial work measurement standards. Finally, a method must be established to obtain the priorities of maintenance for each PEI and SDR. These priorities will serve as the objective function coefficients for the linear program that will be utilized to achieve the optimal resource allocation. These vectors will then be arranged into a tableau and input into the aforementioned linear program. This will yield the optimal mix of PEI's and SDR's that should be rebuilt at each DMA during the Five Year Maintenance Defense Plan. These estimated numbers of PEI's and SDR's can then be priced out against the average cost to repair each individual item giving the required budget estimations.

IV. BUDGETING PROCESS

The purpose of the budget process is to allocate scarce resources among competing public demands in order to seek attainment of objectives. Budgeting is geared to a cycle which allows the system to absorb and respond to new information. The cycle has four main phases: (1) executive formulation; (2) congressional enactment; (3) budget execution; and (4) audit. Each of these phases interrelates and overlaps the others. Figure 5 depicts the first three phases of the budget process and divides the first phase, executive formulation, into the planning, programming and budgeting stages of DoD's formulation process. As shown, there are always three different fiscal year budgets active. [Ref. 5]

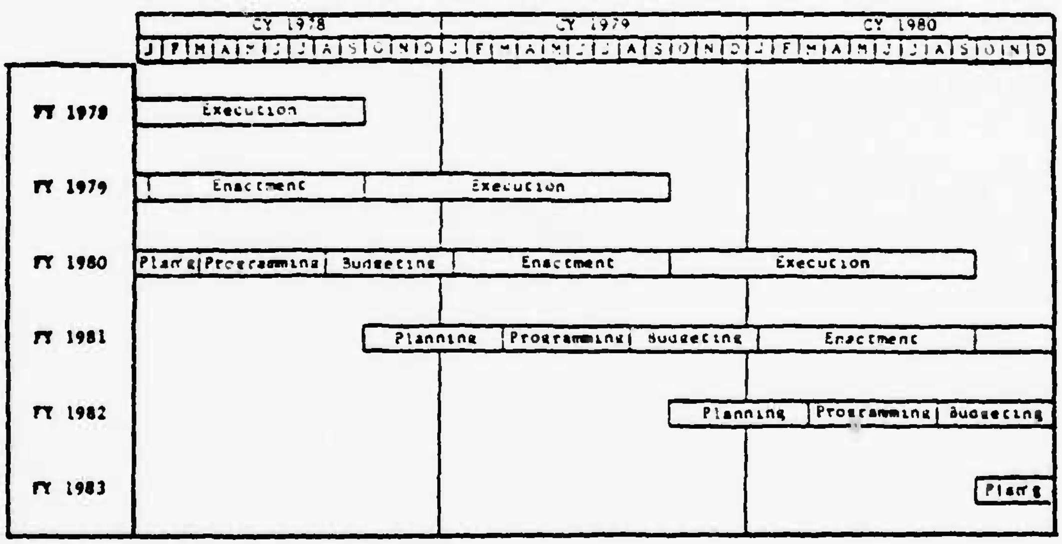

Figure 5. Three Phases of Budget Process

A. APPROPRIATION AND PROGRAM BUDGETS

The DoD budget is divided into two parts. First in terms of input of resources, described in the appropriation format, and secondly, in terms of output, described in the program format.

1. Appropriation Format

An appropriation is an authorization, by Act of Congress, to incur obligations for specific purposes and make payment therefore out of the Treasury. Appropriations can be categorized in at least three different ways; as to purpose (either expense or investment); as to duration (annual or multiple years); and as to the level of funding (either incrementally or fully funded).

2. Program Format

Traditional budgeting is concerned with the input of resources while program budgeting is concerned with the output of programs. The program budget sets forth what accomplishments can be expected from the resources made available.

The building block of the Program Budget is the Program Element. A Program Element is a grouping of forces, manpower and costs associated with an organization, a group of similar organizations, a function or a project. Each Program Element will normally consist of forces, manpower and costs.

The Program Element concept allows the operating manager to participate in the programming decision process since both the inputs and outputs are stated and measured in Program Element terms. Similar program elements are aggregated, or grouped, into major programs. The ten major programs (output) and their support appropriations (input) comprise

the Five Year Defense Program (FYDP). They are as follows:

Program 1 - Strategic Forces
Program 2 - General Purpose Forces
Program 3 - Intelligence and Communications
Program 4 - Airlift and Sealift
Program 5 - Guard and Reserve Forces
Program 6 - Research and Development
Program 7 - Central Supply and Maintenance
Program 8 - Training Medical and Other General Personnel Activities
Program 9 - Administrative and Associated Activities
Program 0 - Support of Other Nations

These ten programs are conceptualized in Figure 6.

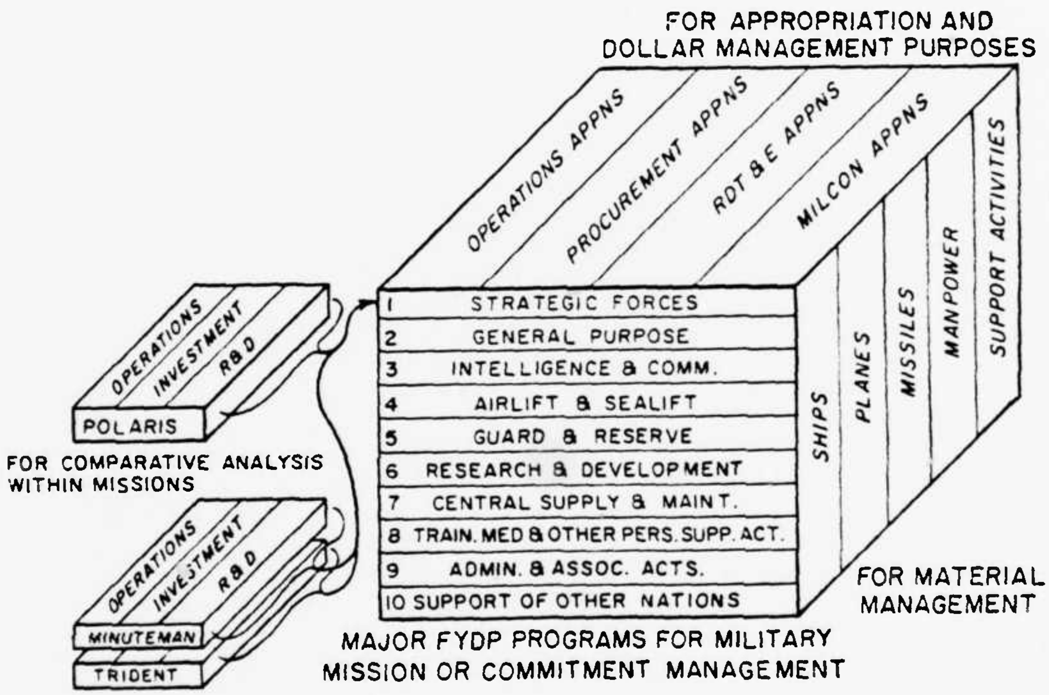

Figure 6. Concept of DOD Programming System

The Five Year Defense Program is the publication that records, summarizes and displays the decisions that have been approved by the SECDEF as constituting the DoD's program. It is a management tool that keeps management informed of what has been accomplished in the past and what is to be accomplished in the future to support the national strategy decisions. The FYDP is updated at least three times a year; in October, after Congress has enacted new fiscal year Appropriations Bills, in January based on the President's submittal of his FY+1 Budget and in May based on the Program Objective Memorandum (POM).

B. PLANNING, PROGRAMMING AND BUDGETING SYSTEM

The Planning, Programming and Budgeting System is simply a decision making process for allocating defense resources. It takes almost two years and involves four major players at the Washington D.C. level (i.e., OMB, OSD, JCS, the Services) who, through an iterative process move from broad planning considerations, to more definitive program objectives to finally specific budget estimates which price out the programs. In the simplest of terms, PPBS is a system designed to assist the Secretary of Defense in making choices about the allocation of resources among a number of competing or possible programs and alternatives to accomplish specific objectives in our national defense.

The Planning, Programming, and Budgeting System contrasts with the traditional budgeting process which preceded it in two significant ways. First, PPBS tends to focus less on the existing base and annual incremental improvements to it. Instead, its focus is more on objectives and purposes, and the long-term alternative means for achieving them. As a result of this emphasis, planning has been elevated to a level on par

with budgetary management and control. Secondly, the system brings together planning and budgeting by means of programming, a process which essentially defines a procedure for distributing available resources equitably among the many competing or possible programs.

The PPBS process is depicted in Figure 7 and is described as follows:

1. Planning

Planning, the first phase of the PPBS starts with the assessment of the threat to the security of the United States and, when combined with national policy, culminates in the development of force objectives to assure the security of the United States. In the context of the PPBS annual cycle, planning is initiated with the submission of the Joint Strategic Planning Document (JSPD) by the JCS and ends with the Secretary of Defense's issuance of the Defense Guidance which is the document providing guidance for preparation of the Program Objectives Memoranda. The JSPD provides the advice of the JCS to the President, the National Security Council, and the Secretary of Defense on the military strategy and force structure required to attain the national security objectives of the United States.

2. Programming

The basic purpose of the programming phase in PPBS is to translate the strategy into program force structures in terms of time-phased resources requirements including personnel, monies, and material. This is accomplished by systematic approval procedures that "cost out" force objectives for financial and manpower resources five years into the future.

The critical document during the Program Phase is the Program Objectives Memorandum (POM). POM's are prepared by each of the Services

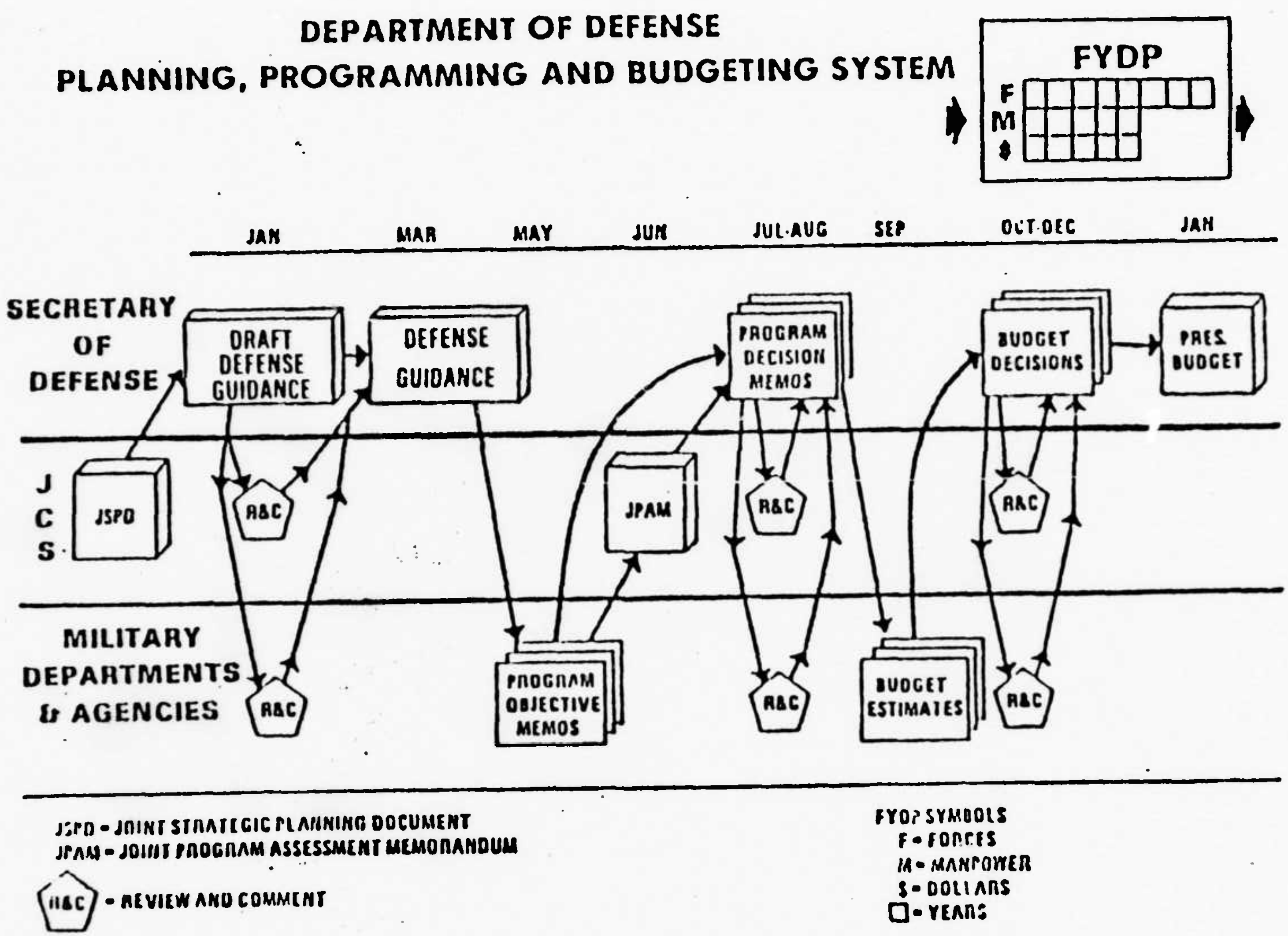

Figure 7. DoD Planning, Programming and Budgeting System

in response to the Defense Guidance from SECDEF. The purpose of a POM is to express total program requirements in terms of force structure, manpower, material and costs, to satisfy all assigned functions and responsibilities during the period of the Five Year Defense Plan. The POM provides rationale for changes from the approved FYDP base and is the primary means of requesting revision to the SECDEF approved programs as published in the FYDP.

About 30 days after the Service's publish their Program Objective Memoranda, the JCS issue the Joint Program Assessment Memorandum (JPAM). The JPAM gives the views of the Joint Chiefs on the adequacy of the composite force and resource levels presented in the Service POMs. The SECDEF considers the Joint Chief's analyses when deciding program issues during the summer issue cycle preceding final approval of Service POMs and the drafting of Program Decision Memoranda (PDM).

As a prelude to the promulgation of the Program Decision Memoranda (PDM), program issues related to force levels, system acquisition, and rates and levels of support are addressed by the OSD and Service Staffs in issue papers which are OSD analyses of annual POM submittals. SECDEF decisions resulting from this review process are promulgated in the Program Decision Memorandum (PDM). Major issues identified in the PDM are discussed by the Service Chiefs, Service Secretaries, and SECDEF.

3. Budgeting

Budgeting is the final phase in the Planning, Programming, Budgeting cycle. The annual budget expresses the financial requirements necessary to support approved programs which were developed during the preceding phases of planning and programming. It is through the

budget that planning and programming are translated into annual funding requirements.

Budget Estimates are submitted to OSD for analyses. After the analyses, the SECDEF holds a series of budget hearings attended by DoD components, the OJCS, and OMB. These hearings are used by SECDEF to formulate his decisions on Decision Package Sets (DPS), which have been prepared by OSD. After OSD issues the annual DPSs, the Services and OJCS provide comments on the DPSs to SECDEF. These comments received from the various components are used by OSD to prepare revised DPSs. At this point, the Budget Estimate if finalized, which after approval by the SECDEF is submitted to OMB for incorporation into the President's Budget.

V. WORK UNIT MEASUREMENT

A. BACKGROUND

For many years the Department of Defense, along with many industries in the private sector, has recognized the importance of quantifying the duration of manual activity to determine the "should take" time to perform that activity, and for establishing a standard method of accomplishment and an associated time value that can be applied whenever and wherever the task or job occurs. Associating of predetermined times to work being measured is standard time data and is generally accepted as the most efficient and productive technique of work measurement. [Ref. 6] DoD, in the late 1960s, began a program to consolidate existing standard data into a common format and publish it so that a single source of standard time data would be available to all DoD activities. This task was completed in 1974 with the publication of DoD 5010.15.1-M, Standardization of Work Measurement. The program has successfully provided a single source of standard time data for use throughout DoD, and efforts to enlarge the coverage and improve the quality of the data are continuing.

As the quantity of standard time data grew and their use increased, problems began to appear. Primarily, the ability to store, search, and retrieve data became increasingly difficult, costly and time consuming. Many of the benefits gained from the use of the data were eroded by the sheer volume of data that had to be stored, searched, retrieved and manipulated.

In the late 1970s a study was initiated to determine a more economical and efficient means of handling standard time data. A method was

needed that would free the work measurement analyst/industrial engineer from the time consuming manual application and maintenance of standard time data so that more time could be devoted to other efforts to improve DoD productivity, e.g., cost reduction, performance analysis, methods improvement. Utilization of a computer as an aid toward the generation of time standards appeared to be the most logical and effective approach to achieve this objective.

In the fall of 1978, DoD contracted with Computer Sciences Corporation to conduct a study to determine the feasbility of computer-aided application of standard time data. Following a review and evaluation of the study, it was concluded that a computer-aided system to establish time standards was not only desirable but feasible as well. Specifications, requirements, and details of a proposal to accomplish the automation of a standard time data application system were developed and a Request for Proposals (RFP) was issued in the spring of 1981. This resulted in the award of a contract to Computer Sciences Corporation, INFONET in September of 1981. This contract was for the initial development, testing, evaluation, and implementation on CSC timesharing (INFONET) of the Defense Computer Aided Standard Data Application System (DCASDAS), more simply called CATS (Computer Aided Time Standards).

B. CATS SUMMARY

CATS provides users with a computer-aided methodology to rapidly find and systematically use standard time data and existing standards to construct new time standards. Various data bases and files containing data essential to the construction of these standards can be

accessed through a remote computer terminal. The operations are performed in an interactive mode.

The prime objective in the design of CATS was to provide, in a user-friendly, conversational format, the means to rapidly find and retrieve work measurement data and to perform the required mathematical computations. Thus, much of the tedium and ineffectiveness inherent in the manual accomplishment of these functions was eliminated. [Ref. 7]

Authorized standard time data and standards will now be available to all DoD users. This capability provides users access to a much wider range of data in a much faster mode than has been previously possible. CATS uses a series of menus, prompts, and instructions displayed at the terminal to direct the operator to appropriate standard time data or standards and then, when the data is found, leads the operator through the necessary processes to construct a new standard.

Procedures to assure control and access to the data bases are established by the using DoD proprietary component. Access as well as the capability to change or modify any data rests with the various system managers. Data stored in any of the "local" data bases can be made available for review for possible inclusion in the DoD data base at the discretion of the system managers through the telecommunication capabilities of CATS.

An essential function of this system is the rapid generation of high-level standards for staffing determinations, staffing projections, and work planning and control. The system will accomplish this by allowing application of locally developed elements or standards as an integral part of its operation.

To increase the flexibility of operation, the development is modular so that "add ons" designed to enhance operations can be made part of the system quickly and inexpensively. Some of the possible "add on" modules are a procedure for developing standard costs, a technique for making an interactive real time cost or procedure comparison, and the capability to automatically determine the effects of efficiency or productivity improvements.

CATS, as developed by CSC, will operate initially on the INFONET timesharing network and will utilize the MANAGE data base management system. By operating on INFONET, worldwide, 24 hour-a-day access to the system is available along with the technical support available from such an organization. By using a common network, DoD components have access to a much larger quantity of standard data elements and standards. It should be noted that the system is designed so that it can be converted for use with other data base management systems, either "in-house" or another timesharing service.

C. METHODOLOGY

As previously stated, CATS could be used either through the CSC INFONET timesharing mode or through an "in-house" mode given that ample computer hardware was available. The initial CATS cost-benefit analysis supported the idea that cost savings could be maximized if the end user could load the system locally. The Marine Corps is currently converting to a data base management concept at its data processing installations and is currently in the process of buying the new hardware required. This concept allows for the arrangement of data in a hierarchial structure that provides for real-time processing and on-line inquiry.

The new large mainframe AMDAHL computers are already in place and operating in Albany, Washington and Kansas City, and delivery to the remaining sites is in the near future.

If the CATS data base management system was locally available at the Depot Maintenance Activities, a program could be written to extract the total time and skill levels required in the major rebuild of each piece of ground equipment. When coupled with the total manhours resident in the personnel data base at each depot, one has all the input coefficients needed for the optimization of the workload within the Master Work Schedule via a linear program utilization.

VI. FORECASTING REBUILD REQUIREMENTS

A. BACKGROUND

Marine Corps Order P4790.1 established MIMMS as the ground equipment maintenance program throughout the Marine Corps. MIMMS is an integrated management system encompassing all equipment commodity, based on standard policies and procedures. These policies and procedures are applicable at all levels of command and echelons of maintenance. When properly used, it contributes significantly to increased equipment readiness and reduces consumption of maintenance resources. It is user-oriented and designed to interface with other logistical systems. [Ref. 8]

MIMMS is comprised of three subsystems that include Headquarters, Depot and Field as depicted in Figure 8.

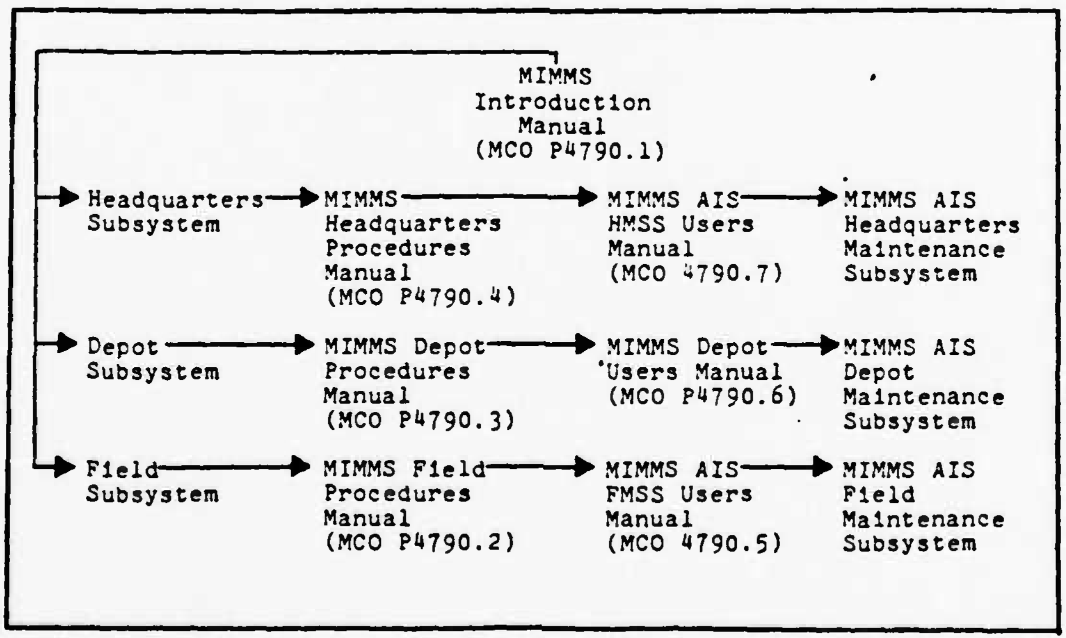

Figure 8. MIMMS Subsystems

1. Headquarters Subsystem

The Headquarters subsystem was developed to support and guide personnel at Headquarters Marine Corps. The Automated Information System (AIS) subsystem supporting the Headquarters maintenance management is the MIMMS AIS Headquarters Maintenance System (HMSS).

2. Depot Subsystem

The Depot subsystem supports the Depot maintenance effort and it utilizes the Depot Maintenance Subsystem (DMSS) as its supporting AIS subsystem.

3. Field Subsystem

The Field subsystem supports the end user in the Fleet Marine Force. Its supporting AIS subsystem is called the Field Maintenance Subsystem (FMSS).

B. METHODOLOGY

The relatively small size of the Marine Corps allows for the compilation of large amounts of historical data on ground equipment items. Presently, all serial numbered items, including Principal End Items and Secondary Depot Repairables, are tracked throughout their life cycle.

1. Accumulation of Data

The major problem remaining at this point in the model is the identification and transferring of appropriate historical records to the logistic support sponsors at Albany, Georgia. This can be accomplished via the maintenance engineering code currently being used in the Fleet Marine Force. This code presently identifies equipment records that are to be extracted and sent to Headquarters for use in the Headquarters Maintenance Subsystem on a periodic basis. This code could also be

used, with very little program modification, to identify and segregate records to be sent to Albany. Once accomplished, this will allow for the aggregation and storage of all maintenance data on all Marine Corps Principal End Items and Secondary Repairables at one common location.

2. Multiple Linear Regression

It is at this point that the mathematical techniques of multiple regression can be brought into play. Regression has become a widely accepted tool for cost analysis and forecasting, and it is frequently used to develop estimating relationships within the Department of Defense. The technique of regression analysis can be thought of as consisting of two distinct stages. The first is that of estimating the constant and coefficients of the equation, and the second is that of inferring the reliability and significance of the results of the estimate on the basis of assumed, and to a degree verifiable, properties possessed by the data and the results. Regression analysis as a technique is applicable only to the two stages performed together. [Ref. 9]

The form of the relationships between the dependent and the explanatory variables will always depend on the particular problem under consideration. It may reflect either an underlying physical law or a structural relationship. The linear model addressed in this thesis will be of the form:

$$z = ax+by+c$$

where z is the dependent variable (the variable we are attempting to estimate) and x and y are both explanatory variables. These explanatory variables will be considered as engine operating time and total labor hours respectively. The symbols a and b are the regression coefficients,

and the symbol c is the regression constant. In layman's language, if we process all the historical maintenance data for a particular piece of ground equipment through a multiple regression program, the historical representations of engine operating time (x) and total labor hours (y) to major rebuild will yield the regression coefficients a and b, along with the regression constant c. Then, given the engine operating time (x) and total labor hours (y) of a like piece of equipment still in use, we can estimate the time (z) when this given piece of equipment will require overhaul. This date will then be checked against the service exit date for that particular serial numbered item to assure its candidacy for rebuild. The regression analysis will also yield information than can be used to infer the confidence of our prediction. This work will all be instrumental in attempting to calculate approximately the quantity of each type of equipment requiring rebuild over the Five Year Defense Plan. It should be noted at this time as a by-product, these quantities could be input into the Interim Material Management Programming Model for use in the requirements calculations as previously stated.

Simplicity dictates that I use the actual output of the regression analysis as the input to the latter stages of this model. However, one should realize that these quantities of Principle End Items and Secondary Depot Repairables may be altered before induction into any linear program.

3. <u>Alterations of Regression Analysis</u>

There are many managerial decisions that might alter the actual output quantities of the regression analysis. The following list shows five such decisions that a logistics planner might have to account for:

1. Particular priority to a given type of equipment to meet requirement shortfalls.

2. Transportation delays of the equipment to the supporting Depot Maintenance Activity.

3. Carcass returns left over from previous year.

4. Alteration of Master Work Schedule to satisfy some special project.

5. Rebuild requirements of other services for like equipment.

Of these particular five, the first four are more or less self-explanatory. However, other services' rebuild requirements should be embellished upon.

a. Nonconsumable Item Program

During February 1974, the Joint Logistics Commanders of the Department of Defense directed that their Joint Policy Coordinating Group for Defense Integrated Material Management (JPCG/DIMM) eliminate unnecessary duplication in the management and logistics support of multi-used nonconsumable items. The JPCG/DIMM identified material management of all reparable nonconsumable items used by two or more services and assigned the material management responsibilities in favor of the service with the largest maintenance and depot maintenance capability to support the item. This assignment included functions of computations of replacement and overhaul requirements, budgeting and funding, procurement, receipt, storage and issue, depot level maintenance, cataloguing and disposal. [Ref. 10]

Implementation of this program resulted in the establishment of the Nonconsumable Item Program in March of 1978. A lead service was designated the Primary Inventory Control Activity (PICA) for each nonconsumable item on file at the Defense Logistics Service Center with the exception of multi-used, nonconsumable items identified as interchangeable and substitutable (I&S) and items under management cognizance of the Defense Nuclear Agency (DNA). A one-digit code was added to the

DLSC files. An alpha code designed where and by whom rebuild could be performed and a numeric code identified on agreed-to type of support between the Primary Inventory Control Activity and the Secondary Inventory Control Activity (SICA).

b. Secondary Inventory Control Activity (SICA)

The responsibilities of the Secondary Inventory Control Acitivity are as follows:

1. Submitting request for procurement of items to the assigned PICA.

2. Notifying the PICA of service excesses and taking appropriate disposition action.

3. Negotiating with the PICA the degree of support to be provided.

4. Providing the PICA, on a cyclic basis, projected requisitioning requirements and projected unserviceable carcass returns.

5. Initiating action to update the federal file with the applicable Nonconsumable Item Material Support Code (NIMSC).

6. Submitting to the PICA proposed cataloguing changes to data which is under the PICA's cognizance.

7. Establishing service requirements.

8. Budgeting and funding for service requirements in accordance with material support codes assigned.

The size limitations of the Marine Corps dictate that it be designated the Secondary Inventory Control Activity on virtually every piece of equipment contained within the Tables of Equipment. For this reason, it is of utmost importance that the depots keep in close contact with their representatives at the Maintenance Interservice Support Management Office (MISMO).

c. Maintenance Interservice Support Management Office (MISMO)

The MISMO is a collection of interservice representatives that serve as the communications link between PICA - SICA activities. It is within this office that the Marine Corps makes agreements to re-build much of their own ground equipment at their own Depot Maintenance Activities. They also make agreements with other services to handle some of the overflow created by other services. Marine Corps Master Work Schedule planners at Albany must keep in constant communication with their MISMO representatives in order to effect meaningful alterations to the regression analysis output.

VII. MODEL ANALYSIS

The following paragraphs are a synopsis of the FORTRAN program that was personally written and utilized to calculate the regression coefficients used to estimate the number of carcass returns that would be candidates for rebuild during each year of the Five Year Defense Plan. In addition, the results of a survey used to establish objective function coefficients for the final linear program execution are provided.

A. GENERATION OF MAINTENANCE DATA

The purpose of this paper is to demonstrate some quantitative methods for estimation and optimization. Because of this, it was deemed unnecessary to utilize actual maintenance data. A random number generator was used to generate standard normal deviates which were in turn transformed into normal random deviates. These deviates were used to emmulate time to major rebuild, equipment operating time, and total labor hours spent in third and fourth echelon maintenance at the Force Service Support Groups (FSSG's) before rebuild. This set of data represented information that would be available within the MIMMS AIS Depot Maintenance Subsystem and was utilized as input to a multiple linear regression subroutine. The outputs of this program execution were the regression coefficients contained in Figure 9.

A second set of deviates were then generated to emmulate equipment operating times and total labor hours of Marine Corps ground equipment presently active within the FMF. The information is presently available within the MIMMS AIS Field Maintenance Subsystem. This data was then

REGRESSION COEFFICIENTS

	TANKS	AMTRACKS	RADIOS	TRUCKS	HOWITZERS
BETA(1)=	-0.003725	0.101428	-0.081089	0.115988	-0.037267
BETA(2)=	0.221236	-0.094033	0.312172	-0.010870	0.159418
BETA(3)=	17.257538	31.995407	17.386505	26.666733	17.246368

ESTIMATED NUMBER OF MONTHS BEFORE MAJOR REBUILD

TANKS	AMTRACKS	RADIOS	TRUCKS	HOWITZERS
7.92	24.96	16.09	22.90	48.35
28.68	46.06	1.68	41.47	48.48
9.80	30.48	15.32	58.05	20.97
14.69	25.43	57.61	13.05	15.39
21.86	50.39	43.85	5.00	36.96
33.81	35.82	32.79	24.75	19.87
49.25	34.06	38.49	43.12	26.91
26.00	17.23	15.19	22.20	61.02
21.82	10.40	35.21	20.92	12.26
1.93	24.00	42.29	29.91	34.36
37.67	48.48	17.74	45.32	30.43
40.02	43.43	4.95	42.50	3.57
58.12	33.32	17.07	33.06	1.43
17.81	3.60	62.91	24.14	36.22
17.54	30.90	16.60	31.55	25.61
44.36	6.01	2.27	19.84	24.99
28.07	11.82	94.66	6.43	22.39
18.80	9.01	16.87	54.58	20.50
9.85	23.94	62.87	44.61	9.10
44.00	32.20	21.63	24.64	4.52
5.93	33.95	7.27	37.66	32.37
49.23	25.10	33.99	4.11	12.98
64.61	44.79	42.25	58.46	3.83
2.22	35.63	42.21	13.45	22.07
5.25	20.52	70.55	23.40	41.04
10.93	45.04	46.25	19.64	19.44
22.63	34.50	48.09	23.67	32.48
24.31	52.42	33.58	20.89	24.72
11.87	36.52	21.04	4.07	12.42
49.96	18.64	5.64	8.24	5.37
32.60	35.66	40.59	30.54	33.70
29.65	51.71	39.76	42.09	18.61
39.00	34.84	35.54	48.34	42.56
57.01	20.00	2.88	47.39	15.07
10.22	47.62	35.20	29.35	13.89
8.49	35.50	5.93	42.14	11.18
27.77	41.62	76.77	42.08	6.88
0.01	36.53	39.82	26.86	5.92
44.35	13.04	94.30	54.00	16.60
53.22	34.15	7.06	19.30	2.82
27.19	17.99	54.40	23.38	45.61
53.72	1.53	35.01	17.70	29.35
55.06	38.95	47.22	25.69	27.84
9.56	53.12	43.84	46.16	8.58
24.08	13.12	13.07	33.57	2.24
52.10	31.35	10.63	14.06	8.05
7.40	49.37	53.54	40.27	26.73
8.41	27.96	27.11	36.10	40.17
8.24	22.86	15.21	13.03	3.65
12.17	50.70	24.66	10.08	3.80

Figure 9. Regression Coefficients and Estimated Number of Months Before Major Rebuild

applied to the above mentioned regression coefficients yielding the approximate month that the individual serialized equipment would require major rebuild. These months to major rebuild are shown in Figure 9 and represent the number of months until a piece of equipment, presently in use, will require major overhaul.

The estimated number of months to major rebuild were then aggregated by commodity within five different twelve month intervals yielding the results shown in Figure 10. These results were then used as input to the linear programming model.

It should be noted that due to the scope of this paper, only five major categories are presented herein:

1. Tanks
2. Amtracks
3. Radios
4. Trucks
5. Howitzers

However, these quantitative techniques apply to all categories of Marine Corps ground equipment as well as all models within the categories.

B. OBJECTIVE FUNCTION

Before the linear program can be executed using the rebuild candidates, skill level hours available and skill level hours required, an objective function must be formulated. Obviously, the five major commodities are the variables but the corresponding coefficients must be determined. These coefficients represent the level of importance associated with the rebuild of each commodity, and are used to insure the maximization of depot productivity for the labor skill levels

AGGREGATED REBUILD CANDIDATES

	TANKS	AMTRACKS	RADIOS	TRUCKS	HOWITZERS
YEAR(0)	16	6	9	6	15
YEAR(1)	8	10	11	15	14
YEAR(2)	10	18	9	11	12
YEAR(3)	6	9	11	13	6
YEAR(4)	9	7	4	5	2

Figure 10. Aggregated Rebuild Candidates

available. A survey was used to determine these objective function coefficients.

Twenty Marine and Army officers were asked to rank the aforementioned commodities in their order of importance to the ground forces. The method utilized to analyze these rankings is one in which ordinal information furnished by judges is combined with a model of judge behavior to obtain, ultimately, an interval scale for the instances (commodities). Thus, while an individual judge may be asked only to rank instances, collective inputs from many judges permit an interval scale to be inferred without arbitrary scoring. Models approaching scale development from ordinal data vary depending upon the assumptions made. The model utilized herein is described in Ref. 11.

A FORTRAN program was then written to carry out the mathematics required by the reference. Once these results were calculated, a linear transformation was then applied to initialize the lowest value to 1.0. These final objective function coefficients are shown in Figure 11 along with the corresponding f(i,j), p(i,j) and z(i,j) matrices required in the calculations. The f(i,j) matrix shows the number of times that the i instance was ranked above the j instance by all judges. The p(i,j) matrix then breaks these values into probabilities through the use of the formula

$$p(i,j) = f(i,j) \;/\; (f(i,j) + f(j,i))$$

Finally, the z(i,j) matrix is computed by standard normalizing the p(i,j) matrix. It should be noted at this point that the linear transformation chosen in the project is not unique and will not yield unique results when the objective function and input tableau are input to the

F(I,J) MATRIX

0.0	14.0	20.0	24.0	24.0
26.0	0.0	22.0	20.0	24.0
20.0	18.0	0.0	18.0	20.0
16.0	20.0	22.0	0.0	24.0
16.0	16.0	20.0	16.0	0.0

P(I,J) MATRIX

0.50	0.35	0.50	0.60	0.60
0.65	0.50	0.55	0.50	0.60
0.50	0.45	0.50	0.45	0.50
0.40	0.50	0.55	0.50	0.60
0.40	0.40	0.50	0.40	0.50

Z(I,J) MATRIX

0.0	-0.39	0.0	0.25	0.25
0.39	0.0	0.13	0.0	0.25
0.0	-0.13	0.0	-0.13	0.0
-0.25	0.0	0.13	0.0	0.25
-0.25	-0.25	0.0	-0.25	0.0

OBJECTIVE FUNCTION COEFFICIENTS

TANKS	AMTRACKS	RADIOS	TRUCKS	HOWITZERS
1.1763	1.3049	1.1017	1.1771	1.0000

Figure 11. Objective Function Coefficients

linear program. This is merely one of the many ways of deriving the objective function coefficients.

C. LINEAR PROGRAMMING

Linear programming has long been recognized as a mathematical tool which allows for the accomplishment of some mission through the most efficient use of resources available. [Ref. 12] These linear programming packages are commercially available and are widely used throughout the Department of Defense. In this project, the mission is to find the optimal mix of equipment to rebuild utilizing the resources, labor hours within different skill levels, available at the Depot Maintenance Activity. While one would intrinsically expect to achieve integer answers, the linear program will more than likely yield fractionalized results. However, since the quantities we are dealing with are relatively large compared to zero or one, the results can be rounded down to the next smaller integer to insure compliance with existing labor availability constraints. This can be accomplished without significant loss of accuracy and is perfectly acceptable since we are only interested in estimating numbers of equipment to be rebuilt.

The tableau of coefficients to be input into the linear program is pictured in Figure 12. The column headings (i.e., tanks, amtracks, radios, trucks, howitzers) represent the variables we are attempting to maximize. The coefficients under the column headings represent the number of hours within each skill level required to rebuild the item represented by that particular column heading. This information was extracted from the CATS files previously mentioned. The coefficients

MAXIMIZE $1.1763X(1) + 1.3049X(2) + 1.1017X(3) + 1.1771X(4) + 1.0000X(5)$

Subject To:

X(1) Tanks	X(2) Amtracks	X(3) Radios	X(4) Trucks	X(5) Howitzers		
20	25	42	28	30	12480	(WG- 6 Electrician)
28	42	35	25	40	14560	(WG- 7 Electrician)
43	22	26	47	40	10400	(WG- 8 Electrician)
29	34	28	44	32	20800	(WG- 9 Electrician)
23	26	41	33	48	12480	(WG-10 Electrician)
24	26	38	25	43	14560	(WG-11 Electrician)
34	46	27	23	21	20800	(WG-12 Electrician)
30	20	26	43	37	16640	(WG- 6 Mechanic)
28	24	34	42	48	18720	(WG- 7 Mechanic)
34	43	41	22	28	20800	(WG- 8 Mechanic)
31	23	26	46	42	14560	(WG- 9 Mechanic)
20	29	35	43	27	10400	(WG-10 Mechanic)
25	35	42	30	22	16640	(WG-11 Mechanic)
32	32	40	28	24	10400	(WG-12 Mechanic)
45	40	23	27	34	20800	(WG- 6 Armorer)
27	35	37	32	20	12480	(WG- 7 Armorer)
21	43	48	29	30	20800	(WG- 8 Armorer)
20	34	36	42	27	14560	(WG- 9 Armorer)
43	34	38	22	44	10400	(WG-10 Armorer)
25	23	38	42	21	18720	(WG-11 Armorer)
30	42	21	22	29	16640	(WG-12 Armorer)
36	28	20	42	47	12480	(WG- 6 Machinist)
31	46	27	37	30	20800	(WG- 7 Machinist)
25	26	38	43	48	10400	(WG- 8 Machinist)
34	35	22	47	27	12480	(WG- 9 Machinist)
23	21	28	40	31	16640	(WG-10 Machinist)
24	42	43	30	32	16640	(WG-11 Machinist)
20	31	43	29	22	18720	(WG-12 Machinist)
29	34	37	28	25	12480	(WG- 6 Calibration)
21	45	46	31	30	12480	(WG- 7 Calibration)
37	41	28	28	31	18720	(WG- 8 Calibration)
26	35	23	48	23	12480	(WG- 9 Calibration)
30	37	23	46	34	16640	(WG-10 Calibration)
29	28	46	31	30	14560	(WG-11 Calibration)
20	36	34	32	29	12480	(WG-12 Calibration)
37	47	31	30	25	20800	(WG- 6 Hydraulics)
23	24	45	47	33	16640	(WG- 7 Hydraulics)
34	30	26	42	40	18700	(WG- 8 Hydraulics)
25	28	23	40	34	16640	(WG- 9 Hydraulics)
21	45	44	34	27	12480	(WG-10 Hydraulics)
20	38	34	41	29	14560	(WG-11 Hydraulics)
27	37	41	49	33	18720	(WG-12 Hydraulics)

Figure 12. Linear Programming Tableau

on the right hand side corresponding to the skill level hours required, represent the total skill level hours available and are obtained from the DMA's personnel files.

D. DMA COST ESTIMATION

Once the final results are obtained yielding the optimal mix for rebuild within each commodity for the budget year, the process must be executed for each of the four subsequent years within the Five Year Defense Plan. Upon completion, these results are then multiplied by the historical average cost of rebuild for each separate commodity area thus providing more accurate quantitative estimates for the budget planners.

E. FUTURE ENHANCEMENTS

Several enhancements could be made to this model in an effort to derive more accurate estimates of both costs and rebuild candidates. Since a multiple linear regression package was utilized, any number of explanatory variables (in addition to labor hours and engine operating time) could be used to provide better accuracy. One would merely have to peruse the MIMMS data files available to obtain likely candidates that could have some impact on mean time between overhauls. Also, a regression could be executed in which total rebuild cost would be regressed upon total labor hours and engine operating time. This would probably yield a better cost estimate since it would use data from the actual equipment being rebuilt rather than an average cost to rebuild.

Several more sophisticated enhancements could be made to the current model. One such improvement would provide for the utilization of an

integer linear programming model, serving to further minimize the amount of labor waste within the Master Work Schedule. A cost benefit analysis could prove that the actual increased computer cost of achieving integer results is offset by an increase in productivity within the DMA. Another improvement could provide for a budget planners "knob". This would allow for the comparison of varying levels of depot productivity based on various budget levels. A capability of this type would require the inclusion of an additional vector containing the mean cost of repairs for each commodity area. This vector, along with the input budget level, would then act as another constraint for the linear program.

VIII. CONCLUSIONS

This project was constructed in an attempt to familiarize Marine Corps officials within the Supply community with the mathematical tools available to their commands. In retrospect, this thesis combined information from systems already in and under development, MIMMS and CATS, and applied it to some of the basic tools available to the operations research analyst: random number generation, multiple linear regression, survey analysis and linear programming. Although all of these concepts have been theoretically proven within the academician's world, very few of them are actually put into practice in everyday use. I have shown that these quantitative techniques can be used to significantly improve efficiency at the Depot Maintenance Activity by optimizing the Master Work Schedule through better resource utilization. A follow-on advantage allows these results to actually estimate the total costs within the Depot for the current year and any number of subsequent years. This type of information could prove invaluable to budget planners at the Headquarters level.

This topic was selected for several different reasons. First, it represented an area of some concern to the Supply Operations Division within the Inventory Control Point at Albany, Georgia. [Ref. 13] Secondly, it allowed the presentation of several mathematical techniques in a somewhat modularized approach. The individual reader should be able to conceptualize personal, job-related applications utilizing some of these methods. Finally, this topic provided a vehicle to showcase

the abilities of the operations analyst. It is felt that this type of educational talent should actually be placed at the heart of the aggregated data (the ICP and the DMA's within the Supply field). This would allow for more efficient utilization of the models currently in use through immediate feedback of result analysis. Also, the analyst would have the time and availability to produce newer and better model utilizations. This data availability could serve to effectively minimize the amount of non-productive time for the "on-call" analyst.

APPENDIX A: FORTRAN Regression Analysis Program

```
C       ************************************************************************
C       *                                                                      *
C       *       THIS PROGRAM GENERATES RANDOM DEVIATES TO EMMULATE             *
C       *    REPAIR DATA HELD AT THE DMA. THESE DEVIATES ARE THEN              *
C       *    SUBJECTED TO A MULTIPLE LINEAR REGRESSION TO OBTAIN               *
C       *    THE REGRESSION EQUATION. THE RESULTING COEFFICIENTS               *
C       *    ARE THEN APPLIED TO A SECOND SET OF DEVIATES EMMULAT-             *
C       *    ING REPAIR DATA HELD IN THE FMF,YIELDING APPROXIMATE              *
C       *    TIMES TO REQUIRED REBUILD. THESE FINAL RESULTS ARE                *
C       *    THEN AGGREGATED BY COMMODITY AREA AND YEAR.                       *
C       *                                                                      *
C       ************************************************************************
        REAL*8 DSEED
        REAL  TLH(100),TEOT(100),TMTBF(100),
       *      ALH(100),AEOT(100),AMTBF(100),
       *      RLH(100),REOT(100),RMTBF(100),
       *      DLH(100),DEOT(100),DMTBF(100),
       *      HLH(100),HEOT(100),HMTBF(100),
       *      SD(15),MEAN(15),
       *      TXY(100,7),AXY(100,7),RXY(100,7),DXY(100,7),HXY(100,7),
       *      TBETA(3),ABETA(3),RBETA(3),DBETA(3),HBETA(3),
       *      WK(4)
        INTEGER YR0(5),YR1(5),YR2(5),YR3(5),YR4(5)
        DATA YR0/5*0/
        DATA YR1/5*0/
        DATA YR2/5*0/
        DATA YR3/5*0/
        DATA YR4/5*0/
        DSEED=113366.2000
        NR=100
        CALL GGNML(DSEED,NR,TLH)
        CALL GGNML(DSEED,NR,TEOT)
        CALL GGNML(DSEED,NR,TMTBF)
        CALL GGNML(DSEED,NR,ALH)
        CALL GGNML(DSEED,NR,AEOT)
        CALL GGNML(DSEED,NR,AMTBF)
        CALL GGNML(DSEED,NR,RLH)
        CALL GGNML(DSEED,NR,REOT)
        CALL GGNML(DSEED,NR,RMTBF)
        CALL GGNML(DSEED,NR,DLH)
        CALL GGNML(DSEED,NR,DEOT)
        CALL GGNML(DSEED,NR,DMTBF)
        CALL GGNML(DSEED,NR,HLH)
        CALL GGNML(DSEED,NR,HEOT)
        CALL GGNML(DSEED,NR,HMTBF)
        DO 10 I=1,15
           READ(5,500) SD(I),MEAN(I)
500        FORMAT(F10.6,10X,F10.6)
```

```
10    CONTINUE
      DO 20 I=1,100
         TLH(I)=TLH(I)*SD(1)+MEAN(1)
         TEOT(I)=TEOT(I)*SD(2)+MEAN(2)
         TMTBF(I)=TMTBF(I)*SD(3)+MEAN(3)
         ALH(I)=ALH(I)*SD(4)+MEAN(4)
         AECT(I)=AEOT(I)*SD(5)+MEAN(5)
         AMTBF(I)=AMTBF(I)*SD(6)+MEAN(6)
         RLH(I)=RLH(I)*SD(7)+MEAN(7)
         REOT(I)=REOT(I)*SD(8)+MEAN(8)
         RMTBF(I)=RMTBF(I)*SD(9)+MEAN(9)
         DLH(I)=DLH(I)*SD(10)+MEAN(10)
         DECT(I)=DEOT(I)*SD(11)+MEAN(11)
         DMTBF(I)=DMTBF(I)*SD(12)+MEAN(12)
         HLH(I)=HLH(I)*SD(13)+MEAN(13)
         HEOT(I)=HEOT(I)*SD(14)+MEAN(14)
         HMTBF(I)=HMTBF(I)*SD(15)+MEAN(15)
20    CONTINUE
      DO 30 I=1,100
         TXY(I,1)=TLH(I)
         AXY(I,1)=ALH(I)
         RXY(I,1)=RLH(I)
         DXY(I,1)=DLH(I)
         HXY(I,1)=HLH(I)
         TXY(I,2)=TEOT(I)
         AXY(I,2)=AEOT(I)
         RXY(I,2)=REOT(I)
         DXY(I,2)=DEOT(I)
         HXY(I,2)=HEOT(I)
         TXY(I,3)=TMTBF(I)
         AXY(I,3)=AMTBF(I)
         RXY(I,3)=RMTBF(I)
         DXY(I,3)=DMTBF(I)
         HXY(I,3)=HMTBF(I)
30    CONTINUE
      CALL RLLMV(TXY,100,100,2,0,TBETA,TRMAX,ITER,ITRANK,WK,IER)
      CALL RLLMV(AXY,100,100,2,0,ABETA,ARMAX,ITER,IARANK,WK,IER)
      CALL RLLMV(RXY,100,100,2,0,RBETA,RRMAX,ITER,IRRANK,WK,IER)
      CALL RLLMV(DXY,100,100,2,0,DBETA,DRMAX,ITER,IDRANK,WK,IER)
      CALL RLLMV(HXY,100,100,2,0,HBETA,HRMAX,ITER,IHRANK,WK,IER)
      WRITE(6,700)
      WRITE(6,705)
      WRITE(6,710)
      WRITE(6,720)
700   FORMAT(34X,'REGRESSION COEFFICIENTS')
705   FORMAT('+',33X,'_______________________'//)
710   FORMAT(18X,'TANKS',9X,'AMTRACKS',7X,'RADIOS',10X,'TRUCKS',
     *7X,'HOWITZERS',)
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```
720   FORMAT('+',15X,'_________',7X,'________',6X,'________',8X,
     *'________',6X,'_________'/)
      DO 40 I=1,3
         WRITE(6,730) I,TBETA(I),ABETA(I),RBETA(I),DBETA(I),HBETA(I)
730      FORMAT(2X,'BETA(',I1,')=',5(5X,F10.6))
40    CONTINUE
      NO=50
      CALL GGNML(DSEED,NO,TLH)
      CALL GGNML(DSEED,NO,TEOT)
      CALL GGNML(DSEED,NO,ALH)
      CALL GGNML(DSEED,NO,AEOT)
      CALL GGNML(DSEED,NO,RLH)
      CALL GGNML(DSEED,NO,REOT)
      CALL GGNML(DSEED,NO,DLH)
      CALL GGNML(DSEED,NO,DEOT)
      CALL GGNML(DSEED,NO,HLH)
      CALL GGNML(DSEED,NO,HEOT)
      DO 50 I=1,50
         TLH(I)=TLH(I)*SD(1)+MEAN(1)
         TEOT(I)=TEOT(I)*SD(2)+MEAN(2)
         ALH(I)=ALH(I)*SD(4)+MEAN(4)
         AEOT(I)=AEOT(I)*SD(5)+MEAN(5)
         RLH(I)=RLH(I)*SD(7)+MEAN(7)
         REOT(I)=REOT(I)*SD(8)+MEAN(8)
         DLH(I)=DLH(I)*SD(10)+MEAN(10)
         DEOT(I)=DEOT(I)*SD(11)+MEAN(11)
         HLH(I)=HLH(I)*SD(13)+MEAN(13)
         HEOT(I)=HEOT(I)*SD(14)+MEAN(14)
50    CONTINUE
      WRITE(6,740)
      WRITE(6,745)
      WRITE(6,750)
      WRITE(6,760)
740   FORMAT(/////,20X,'ESTIMATED NUMBER OF MONTHS BEFORE MAJOR REBUILD'
     *)
745   FORMAT('+',19X,'_______________________________________________'//
     *)
750   FORMAT(' ',10X,'TANKS',8X,'AMTRACKS',8X,'RADIOS',
     *9X,'TRUCKS',8X,'HOWITZERS',)
760   FORMAT('+',10X,'_____',8X,'________',8X,'______',
     *9X,'______',8X,'_________'/)
      DO 60 I=1,50
         TMTBF(I)=TBETA(1)*TLH(I)+TBETA(2)*TEOT(I)+TBETA(3)
         AMTBF(I)=ABETA(1)*ALH(I)+ABETA(2)*AEOT(I)+ABETA(3)
         RMTBF(I)=RBETA(1)*RLH(I)+RBETA(2)*REOT(I)+RBETA(3)
         DMTBF(I)=DBETA(1)*DLH(I)+DBETA(2)*DEOT(I)+DBETA(3)
         HMTBF(I)=HBETA(1)*HLH(I)+HBETA(2)*HEOT(I)+HBETA(3)
         TMTBF(I)=ABS(TMTBF(I))
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```
      AMTBF(I)=ABS(AMTBF(I))
      RMTBF(I)=ABS(RMTBF(I))
      DMTBF(I)=ABS(DMTBF(I))
      HMTBF(I)=ABS(HMTBF(I))
      WRITE(6,770) TMTBF(I),AMTBF(I),RMTBF(I),DMTBF(I),HMTBF(I)
770   FORMAT(' ',5(5X,F10.2))
60    CONTINUE
      J=1
      DO 70 I=1,50
      IF((TMTBF(I).GT.0.).AND.(TMTBF(I).LE.12.)) YRO(J)=YRO(J)+1
      IF((TMTBF(I).GT.12.).AND.(TMTBF(I).LE.24.)) YR1(J)=YR1(J)+1
      IF((TMTBF(I).GT.24.).AND.(TMTBF(I).LE.36.)) YR2(J)=YR2(J)+1
      IF((TMTBF(I).GT.36.).AND.(TMTBF(I).LE.48.)) YR3(J)=YR3(J)+1
      IF((TMTBF(I).GT.48.).AND.(TMTBF(I).LE.60.)) YR4(J)=YR4(J)+1
70    CONTINUE
      J=J+1
      DO 80 I=1,50
      IF((AMTBF(I).GT.0.).AND.(AMTBF(I).LE.12.)) YRO(J)=YRO(J)+1
      IF((AMTBF(I).GT.12.).AND.(AMTBF(I).LE.24.)) YR1(J)=YR1(J)+1
      IF((AMTBF(I).GT.24.).AND.(AMTBF(I).LE.36.)) YR2(J)=YR2(J)+1
      IF((AMTBF(I).GT.36.).AND.(AMTBF(I).LE.48.)) YR3(J)=YR3(J)+1
      IF((AMTBF(I).GT.48.).AND.(AMTBF(I).LE.60.)) YR4(J)=YR4(J)+1
80    CONTINUE
      J=J+1
      DO 90 I=1,50
      IF((RMTBF(I).GT.0.).AND.(RMTBF(I).LE.12.)) YRO(J)=YRO(J)+1
      IF((RMTBF(I).GT.12.).AND.(RMTBF(I).LE.24.)) YR1(J)=YR1(J)+1
      IF((RMTBF(I).GT.24.).AND.(RMTBF(I).LE.36.)) YR2(J)=YR2(J)+1
      IF((RMTBF(I).GT.36.).AND.(RMTBF(I).LE.48.)) YR3(J)=YR3(J)+1
      IF((RMTBF(I).GT.48.).AND.(RMTBF(I).LE.60.)) YR4(J)=YR4(J)+1
90    CONTINUE
      J=J+1
      DO 100 I=1,50
      IF((DMTBF(I).GT.0.).AND.(DMTBF(I).LE.12.)) YRO(J)=YRO(J)+1
      IF((DMTBF(I).GT.12.).AND.(DMTBF(I).LE.24.)) YR1(J)=YR1(J)+1
      IF((DMTBF(I).GT.24.).AND.(DMTBF(I).LE.36.)) YR2(J)=YR2(J)+1
      IF((DMTBF(I).GT.36.).AND.(DMTBF(I).LE.48.)) YR3(J)=YR3(J)+1
      IF((DMTBF(I).GT.48.).AND.(DMTBF(I).LE.60.)) YR4(J)=YR4(J)+1
100   CONTINUE
      J=J+1
      DO 110 I=1,50
      IF((HMTBF(I).GT.0.).AND.(HMTBF(I).LE.12.)) YRO(J)=YRO(J)+1
      IF((HMTBF(I).GT.12.).AND.(HMTBF(I).LE.24.)) YR1(J)=YR1(J)+1
      IF((HMTBF(I).GT.24.).AND.(HMTBF(I).LE.36.)) YR2(J)=YR2(J)+1
      IF((HMTBF(I).GT.36.).AND.(HMTBF(I).LE.48.)) YR3(J)=YR3(J)+1
      IF((HMTBF(I).GT.48.).AND.(HMTBF(I).LE.60.)) YR4(J)=YR4(J)+1
110   CONTINUE
      WRITE(6,800)
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      WRITE(6,810)
      WRITE(6,750)
      WRITE(6,760)
800   FORMAT('1',27X,'AGGREGATED REBUILD CANDIDATES')
810   FORMAT('+',27X,'                             ',///)
         WRITE(6,820) YRO(1),YRO(2),YRO(3),YRO(4),YRO(5)
         WRITE(6,821) YR1(1),YR1(2),YR1(3),YR1(4),YR1(5)
         WRITE(6,822) YR2(1),YR2(2),YR2(3),YR2(4),YR2(5)
         WRITE(6,823) YR3(1),YR3(2),YR3(3),YR3(4),YR3(5)
         WRITE(6,824) YR4(1),YR4(2),YR4(3),YR4(4),YR4(5)
820      FORMAT(1X,'YEAR(0)',4X,I2,13X,I2,13X,I2,13X,I2,13X,I2,/)
821      FORMAT(1X,'YEAR(1)',4X,I2,13X,I2,13X,I2,13X,I2,13X,I2,/)
822      FORMAT(1X,'YEAR(2)',4X,I2,13X,I2,13X,I2,13X,I2,13X,I2,/)
823      FORMAT(1X,'YEAR(3)',4X,I2,13X,I2,13X,I2,13X,I2,13X,I2,/)
824      FORMAT(1X,'YEAR(4)',4X,I2,13X,I2,13X,I2,13X,I2,13X,I2,/)
      RETURN
      END
      SUBROUTINE RLLMV  (XY,IXY,N,M,IOPT,BETA,REMAX,ITER,IRANK,WK,IER)
C                                 SPECIFICATIONS FOR ARGUMENTS
      INTEGER            IXY,N,M,IOPT,ITER,IRANK,IER
      REAL               XY(IXY,1),BETA(1),REMAX,WK(1)
C                                 SPECIFICATIONS FOR LOCAL VARIABLES
      INTEGER            IPCOL,IPROW,IRANK1,IROW,I,J,KP1,K,LEV,MM,MODE,
     1                   MP1MK,MP1MR,MP1,MP2,MP3,MP5,NM1,NP1MR
      REAL               BIG,DD,D,FMM,ONE,PIVCT,RELERR,RELTMP,TOL,
     1                   TPIVOT,TWO,VAL,ZERO
      DATA               TOL/Z3C100000/
      DATA               BIG/Z7FFFFFFF/
      DATA               ZERO/0.0/,ONE/1.0/,TWO/2.0/,RELERR/0.0/
C                                 FIRST EXECUTABLE STATEMENT
      MM = M
      MP1 = M+1
      MP2 = M+2
      MP3 = M+3
      MP5 = M+5
      MP1MR = 1
      IRANK = MM
      RELTMP = RELERR
      DO 5 I=1,N
         XY(I,MP5) = XY(I,MP1)
    5 CONTINUE
      IF (IOPT.NE.0) GO TO 15
      DO 10 I=1,N
         XY(I,MP1) = ONE
   10 CONTINUE
      MM = M+1
      MP1 = MM+1
      MP2 = MM+2
```

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      MP3 = MM+3                                                        RLLM1090
      IRANK = MM                                                        RLLM1100
   15 FMM = MM                                                          RLLM1110
      DO 20 J=1,N                                                       RLLM1120
         XY(J,MP1) = CNE                                                RLLM1130
         XY(J,MP2) = -XY(J,MP5)                                         RLLM1140
         XY(J,MP3) = MP+J                                               RLLM1150
   20 CONTINLE                                                          RLLM1160
      WK(MP1) = ZERO                                                    RLLM1170
      ITER = 0                                                          RLLM1180
      IER = 0                                                           RLLM1190
      DO 25 I=1,MM                                                      RLLM1200
         BETA(I) = ZERO                                                 RLLM1210
         WK(I) = I                                                      RLLM1220
   25 CONTINUE                                                          RLLM1230
C                                      LEVEL 1                          RLLM1240
      LEV = 1                                                           RLLM1250
      K = 0                                                             RLLM1260
   30 K = K+1                                                           RLLM1270
      KP1 = K+1                                                         RLLM1280
      MP1MK = MP1-K                                                     RLLM1290
      MODE = 0                                                          RLLM1300
      DO 35 J=K,N                                                       RLLM1310
         XY(J,MP5) = ONE                                                RLLM1320
   35 CONTINUE                                                          RLLM1330
C                                      DETERMINE THE VECTOR TO ENTER THE RLLM1340
C                                        BASIS                          RLLM1350
   40 D = -BIG                                                          RLLM1360
      DO 45 J=K,N                                                       RLLM1370
         IF (XY(J,MP5).EQ.ZERO) GO TO 45                                RLLM1380
         DD = ABS(XY(J,MP2))                                            RLLM1390
         IF (DD.LE.D) GO TO 45                                          RLLM1400
         IPCCL = J                                                      RLLM1410
         C = DD                                                         RLLM1420
   45 CONTINUE                                                          RLLM1430
      IF (K.GT.1) GO TO 50                                              RLLM1440
C                                      TEST FOR ZERO RIGHT-HAND SIDE    RLLM1450
      IF (D.GT.TOL) GO TO 50                                            RLLM1460
      REMAX = ZERO                                                      RLLM1470
      MODE = 2                                                          RLLM1480
      GO TO 205                                                         RLLM1490
C                                      DETERMINE THE VECTOR TO LEAVE THE RLLM1500
C                                        BASIS                          RLLM1510
   50 D = TCL                                                           RLLM1520
      DO 55 I=1,MP1MK                                                   RLLM1530
         CC = ABS(XY(IPCCL,I))                                          RLLM1540
         IF (DD.LE.D) GO TO 55                                          RLLM1550
         IPROW = I                                                      RLLM1560
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      D = DD                                                            RLLM1570
   55 CONTINUE                                                          RLLM1580
      IF (D.GT.TOL) GO TO 180                                           RLLM1590
C                                    CHECK FOR LINEAR DEPENDENCE IN     RLLM1600
C                                      LEVEL 1                          RLLM1610
      XY(IPCOL,MP5) = ZERO                                              RLLM1620
      IF (MODE.EQ.1) GO TO 40                                           RLLM1630
      DO 65 J=K,N                                                       RLLM1640
         IF (XY(J,MP5).EQ.ZERO) GO TO 65                                RLLM1650
         DO 60 I=1,MP1MK                                                RLLM1660
            IF (ABS(XY(J,I)).LE.TOL) GO TO 60                           RLLM1670
            MODE = 1                                                    RLLM1680
            GO TO 40                                                    RLLM1690
   60    CONTINUE                                                       RLLM1700
   65 CONTINUE                                                          RLLM1710
      IRANK = K-1                                                       RLLM1720
      MP1MR = MP1-IRANK                                                 RLLM1730
      IER = 33                                                          RLLM1740
      GO TO 95                                                          RLLM1750
   70 IF (IPCOL.EQ.K) GO TO 80                                          RLLM1760
C                                    INTERCHANGE COLUMNS IN LEVEL 1     RLLM1770
      DO 75 I=1,MP3                                                     RLLM1780
         D = XY(IPCOL,I)                                                RLLM1790
         XY(IPCOL,I) = XY(K,I)                                          RLLM1800
         XY(K,I) = D                                                    RLLM1810
   75 CONTINUE                                                          RLLM1820
   80 IF (IPROW.EQ.MP1MK) GO TO 90                                      RLLM1830
C                                    INTERCHANGE ROWS IN LEVEL 1        RLLM1840
      DO 85 J=1,N                                                       RLLM1850
         D = XY(J,IPROW)                                                RLLM1860
C                                                                       RLLM1870
         XY(J,IPROW) = XY(J,MP1MK)                                      RLLM1880
         XY(J,MP1MK) = D                                                RLLM1890
   85 CONTINUE                                                          RLLM1900
      D = WK(IPROW)                                                     RLLM1910
      WK(IPROW) = WK(MP1MK)                                             RLLM1920
      WK(MP1MK) = D                                                     RLLM1930
   90 IF (K.LT.MM) GO TO 30                                             RLLM1940
   95 IF (IRANK.EQ.N) GO TO 205                                         RLLM1950
      IRANK1 = IRANK+1                                                  RLLM1960
C                                    LEVEL 2                            RLLM1970
      LEV = 2                                                           RLLM1980
C                                    DETERMINE THE VECTOR TO ENTER THE  RLLM1990
C                                      BASIS                            RLLM2000
      D = TOL                                                           RLLM2010
      DO 100 J=IRANK1,N                                                 RLLM2020
         DD = ABS(XY(J,MP2))                                            RLLM2030
         IF (DD.LE.D) GO TO 100                                         RLLM2040
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      IPCCL = J                                                         RLLM2050
      D = DD                                                            RLLM2060
  100 CONTINUE                                                          RLLM2070
C                                 CCMPARE CHEBYSHEV ERROR WITH TOL      RLLM2080
      IF (D.GT.TOL) GC TC 105                                           RLLM2090
      REMAX = ZERC                                                      RLLM2100
      MODE = 3                                                          RLLM2110
      GO TO 205                                                         RLLM2120
  105 IF (XY(IPCOL,MP2).LT.-TOL) GO TO 115                              RLLM2130
      XY(IPCCL,MP1) = TWC-XY(IPCOL,MP1)                                 RLLM2140
      DO 110 I=MP1MR,MP3                                                RLLM2150
         IF (I.EQ.MP1) GO TO 110                                        RLLM2160
         XY(IPCOL,I) = -XY(IPCOL,I)                                     RLLM2170
  110 CONTINUE                                                          RLLM2180
C                                 ARRANGE FOR ALL ENTRIES IN PIVOT      RLLM2190
C                                   COLUMN (EXCEPT PIVOT) TO BE         RLLM2200
C                                   NEGATIVE                            RLLM2210
  115 DO 125 I=MP1MR,MM                                                 RLLM2220
         IF (XY(IPCOL,I).LT.TOL) GO TO 125                              RLLM2230
         DO 120 J=1,N                                                   RLLM2240
            XY(J,MP1) = XY(J,MP1)+TWC*XY(J,I)                           RLLM2250
            XY(J,I) = -XY(J,I)                                          RLLM2260
  120    CONTINUE                                                       RLLM2270
         WK(I) = -WK(I)                                                 RLLM2280
  125 CONTINUE                                                          RLLM2290
      IPROW = MP1                                                       RLLM2300
      GO TO 180                                                         RLLM2310
  130 IF (IRANK1.EQ.N) GO TO 205                                        RLLM2320
      IF (IPCOL.EC.N) GO TO 140                                         RLLM2330
C                                 INTERCHANGE COLUMNS IN LEVEL 2        RLLM2340
      DO 135 I=MP1MR,MP3                                                RLLM2350
         D = XY(IPCOL,I)                                                RLLM2360
         XY(IPCOL,I) = XY(N,I)                                          RLLM2370
         XY(N,I) = D                                                    RLLM2380
  135 CONTINUE                                                          RLLM2390
  140 NM1 = N-1                                                         RLLM2400
C                                 LEVEL 3                               RLLM2410
      LEV = 3                                                           RLLM2420
C                                 DETERMINE THE VECTOR TO ENTER THE     RLLM2430
C                                   BASIS                               RLLM2440
  145 D = -TCL                                                          RLLM2450
      VAL = TWO*XY(N,MP2)                                               RLLM2460
      DO 155 J=IRANK1,NM1                                               RLLM2470
         IF (XY(J,MP2).GE.D) GO TO 150                                  RLLM2480
         IPCOL = J                                                      RLLM2490
         D = XY(J,MP2)                                                  RLLM2500
         MODE = 0                                                       RLLM2510
         GO TO 155                                                      RLLM2520
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150     DD = VAL-XY(J,MP2)                                               RLLM2530
           IF (DD.GE.D) GO TO 155                                        RLLM2540
           MOCE = 1                                                      RLLM2550
           IPCOL = J                                                     RLLM2560
           C = DD                                                        RLLM2570
  155 CONTINUE                                                           RLLM2580
        IF (D.GE.-TCL) GC TO 205                                         RLLM2590
        DD = -C/XY(N,MP2)                                                RLLM2600
        IF (DD.GE.RELTMP) GO TO 160                                      RLLM2610
        RELERR = DD                                                      RLLM2620
        MODE = 4                                                         RLLM2630
        GO TO 205                                                        RLLM2640
  160 IF (MCCE.EQ.0) GO TO 170                                           RLLM2650
        DO 165 I=MP1MR,MP1                                               RLLM2660
           XY(IPCOL,I) = TWO*XY(N,I)-XY(IPCCL,I)                         RLLM2670
  165 CONTINUE                                                           RLLM2680
        XY(IPCCL,MP2) = C                                                RLLM2690
        XY(IPCCL,MP3) = -XY(IPCOL,MP3)                                   RLLM2700
C                                 DETERMINE THE VECTOR TO LEAVE THE      RLLM2710
C                                   BASIS                                RLLM2720
  170 D = BIG                                                            RLLM2730
        DO 175 I=MP1MR,MP1                                               RLLM2740
           IF (XY(IPCOL,I).LE.TOL) GO TO 175                             RLLM2750
           DD = XY(N,I)/XY(IPCOL,I)                                      RLLM2760
           IF (DD.GE.D) GO TO 175                                        RLLM277C
           IPROW = I                                                     RLLM2780
           D = DD                                                        RLLM2790
  175 CONTINUE                                                           RLLM2800
        IF (D.LT.BIG) GO TO 180                                          RLLM2810
        IER = 129                                                        RLLM2820
        GO TO 9000                                                       RLLM2830
C                                 PIVOT CN XY(IPCOL,IPROW)               RLLM2840
  180 PIVOT = XY(IPCOL,IPROW)                                            RLLM2850
        DO 185 J=1,N                                                     RLLM2860
           XY(J,IPRCW) = XY(J,IPROW)/PIVOT                               RLLM2870
  185 CONTINUE                                                           RLLM2880
        DO 195 J=1,N                                                     RLLM2890
           IF (J.EQ.IPCCL) GC TO 195                                     RLLM2900
           D = XY(J,IPRCW)                                               RLLM2910
           DO 190 I=MP1MR,MP2                                            RLLM2920
              IF (I.EQ.IPROW) GO TO 190                                  RLLM2930
              XY(J,I) = XY(J,I)-D*XY(IPCOL,I)                            RLLM2940
  190      CONTINUE                                                      RLLM2950
  195 CONTINUE                                                           RLLM2960
        TPIVCT = -PIVOT                                                  RLLM2970
        DO 200 I=MP1MR,MP2                                               RLLM2980
           XY(IPCOL,I) = XY(IPCOL,I)/TPIVOT                              RLLM2990
  200 CONTINUE                                                           RLLM3000
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```
      XY(IPCOL,IPROW) = ONE/PIVOT                                       RLLM3010
      D = WK(IPROW)                                                     RLLM3020
      WK(IPROW) = XY(IPCOL,MP3)                                         RLLM3030
      XY(IPCOL,MP3) = D                                                 RLLM3040
      ITER = ITER+1                                                     RLLM3050
      GO TO (70,130,145), LEV                                           RLLM3060
C                                      PREPARE OUTPUT                   RLLM3070
  205 DO 210 J=1,N                                                      RLLM3080
         XY(J,MP5) = ZERO                                               RLLM3090
  210 CONTINUE                                                          RLLM3100
      IF (MODE.EQ.2) GO TO 240                                          RLLM3110
      DO 215 J=1,IRANK                                                  RLLM3120
         K = XY(J,MP3)                                                  RLLM3130
         BETA(K) = XY(J,MP2)                                            RLLM3140
  215 CONTINUE                                                          RLLM3150
      IF (MODE.EQ.3.OR.IRANK.EQ.N) GO TO 240                            RLLM3160
      DO 220 I=MP1MR,MP1                                                RLLM3170
         K = ABS(WK(I))-FMM                                             RLLM3180
         XY(K,MP5) = XY(N,MP2)*SIGN(ONE,WK(I))                          RLLM3190
  220 CONTINUE                                                          RLLM3200
      IF (IRANK1.EQ.N) GO TO 230                                        RLLM3210
      DO 225 J=IRANK1,NM1                                               RLLM3220
         K = ABS(XY(J,MP3))-FMM                                         RLLM3230
         XY(K,MP5) = (XY(N,MP2)-XY(J,MP2))*SIGN(ONE,XY(J,MP3))          RLLM3240
  225 CONTINUE                                                          RLLM3250
C                                      TEST FOR NON-UNIQUE SOLUTION     RLLM3260
  230 DO 235 I=MP1MR,MP1                                                RLLM3270
         IF (ABS(XY(N,I)).GT.TOL) GO TO 235                             RLLM3280
         IER = 33                                                       RLLM3290
         GO TO 240                                                      RLLM3300
  235 CONTINUE                                                          RLLM3310
  240 IF (MODE.NE.2.AND.MODE.NE.3) REMAX = XY(N,MP2)                    RLLM3320
      IF (IRANK.EQ.N) REMAX = ZERO                                      RLLM3330
      IF (MODE.EQ.4) REMAX = REMAX-D                                    RLLM3340
      IF (IER.EQ.0) GO TO 9005                                          RLLM3350
 9000 CONTINUE                                                          RLLM3360
      CALL UERTST (IER,6HRLLMV )                                        RLLM3370
 9005 RETURN                                                            RLLM3380
      END                                                               RLLM3390
      SUBROUTINE GGNML  (DSEED,NR,R)                                    GGNH0380
C                                                                       GGNH0390
C                                      SPECIFICATIONS FOR ARGUMENTS     GGNH0400
      INTEGER            NR                                             GGNH0410
      REAL               R(NR)                                          GGNH0420
      DOUBLE PRECISION   DSEED                                          GGNH0430
C                                      SPECIFICATIONS FOR LOCAL VARIABLES GGNH0440
      INTEGER             IER                                           GGNH0450
C                                      FIRST EXECUTABLE STATEMENT       GGNH0460
```

```
C                                     GET NR RANDOM NUMBERS              GGNH0470
      CALL GGUBS(DSEED,NR,R)                                             GGNH0480
C                                     TRANSFORMS EACH UNIFORM DEVIATE    GGNH0490
      DO 5 I=1,NR                                                        GGNH0500
         CALL MDNRIS(R(I),R(I),IER)                                      GGNH0510
    5 CONTINUE                                                           GGNH0520
      RETURN                                                             GGNH0530
      END                                                                GGNH0540
      SUBROUTINE UERTST (IER,NAME)                                       UERT0500
C                                     SPECIFICATIONS FOR ARGUMENTS       UERT0510
      INTEGER            IER                                             UERT0520
      INTEGER*2          NAME(3)                                         UERT0530
C                                     SPECIFICATIONS FOR LOCAL VARIABLES UERT0540
      INTEGER*2          NAMSET(3),NAMEQ(3)                              UERT0550
      DATA               NAMSET/2HUE,2HRS,2HET/                          UERT0560
      DATA               NAMEQ/2H  ,2H  ,2H  /                           UERT0570
C                                     FIRST EXECUTABLE STATEMENT         UERT0580
      DATA               LEVEL/4/,IEQDF/0/,IEQ/1H=/                      UERT0590
      IF (IER.GT.999) GO TO 25                                           UERT0600
      IF (IER.LT.-32) GO TO 55                                           UERT0610
      IF (IER.LE.128) GO TO 5                                            UERT0620
      IF (LEVEL.LT.1) GO TO 30                                           UERT0630
C                                     PRINT TERMINAL MESSAGE             UERT0640
      CALL UGETIO(1,NIN,IOUNIT)                                          UERT0650
      IF (IEQDF.EQ.1) WRITE(IOUNIT,35) IER,NAMEQ,IEQ,NAME                UERT0660
      IF (IEQDF.EQ.0) WRITE(IOUNIT,35) IER,NAME                          UERT0670
      GO TO 30                                                           UERT0680
    5 IF (IER.LE.64) GO TO 10                                            UERT0690
      IF (LEVEL.LT.2) GO TO 30                                           UERT0700
C                                     PRINT WARNING WITH FIX MESSAGE     UERT0710
      CALL UGETIO(1,NIN,IOUNIT)                                          UERT0720
      IF (IEQDF.EQ.1) WRITE(IOUNIT,40) IER,NAMEQ,IEQ,NAME                UERT0730
      IF (IEQDF.EQ.0) WRITE(IOUNIT,40) IER,NAME                          UERT0740
      GO TO 30                                                           UERT0750
   10 IF (IER.LE.32) GO TO 15                                            UERT0760
C                                     PRINT WARNING MESSAGE              UERT0770
      IF (LEVEL.LT.3) GO TO 30                                           UERT0780
      CALL UGETIO(1,NIN,IOUNIT)                                          UERT0790
      IF (IEQDF.EQ.1) WRITE(IOUNIT,45) IER,NAMEQ,IEQ,NAME                UERT0800
      IF (IEQDF.EQ.0) WRITE(IOUNIT,45) IER,NAME                          UERT0810
      GO TO 30                                                           UERT0820
   15 CONTINUE                                                           UERT0830
C                                     CHECK FOR UERSET CALL              UERT0840
      DO 20 I=1,3                                                        UERT0850
         IF (NAME(I).NE.NAMSET(I)) GO TO 25                              UERT0860
   20 CONTINUE                                                           UERT0870
      LEVOLD = LEVEL                                                     UERT0880
      LEVEL = IER                                                        UERT0890
```

```
      IER = LEVOLD                                                      UERT0900
      IF (LEVEL.LT.0) LEVEL = 4                                         UERT0910
      IF (LEVEL.GT.4) LEVEL = 4                                         UERT0920
      GO TO 30                                                          UERT0930
   25 CONTINUE                                                          UERT0940
      IF (LEVEL.LT.4) GO TO 30                                          UERT0950
C                                  PRINT NON-DEFINED MESSAGE            UERT0960
      CALL UGETIO(1,NIN,IOUNIT)                                         UERT0970
      IF (IEQDF.EQ.1) WRITE(IOUNIT,50) IER,NAMEQ,IEQ,NAME               UERT0980
      IF (IEQDF.EQ.0) WRITE(IOUNIT,50) IER,NAME                         UERT0990
   30 IEQDF = 0                                                         UERT1000
      RETURN                                                            UERT1010
   35 FORMAT(19H *** TERMINAL ERROR,10X,7H(IER = ,I3,                   UERT1020
     1       20H) FROM IMSL ROUTINE ,3A2,A1,3A2)                        UERT1030
   40 FORMAT(36H *** WARNING WITH FIX ERROR  (IER = ,I3,                UERT1040
     1       20H) FROM IMSL ROUTINE ,3A2,A1,3A2)                        UERT1050
   45 FORMAT(18H *** WARNING ERROR,11X,7H(IER = ,I3,                    UERT1060
     1       20H) FROM IMSL ROUTINE ,3A2,A1,3A2)                        UERT1070
   50 FORMAT(20H *** UNDEFINED ERROR,9X,7H(IER = ,I5,                   UERT1080
     1       20H) FROM IMSL ROUTINE ,3A2,A1,3A2)                        UERT1090
C                                  SAVE P FOR P = R CASE                UERT1100
C                                    P IS THE PAGE NAME                 UERT1110
C                                    R IS THE ROUTINE NAME              UERT1120
   55 IEQDF = 1                                                         UERT1130
      DO 60 I=1,3                                                       UERT1140
   60 NAMEQ(I) = NAME(I)                                                UERT1150
   65 RETURN                                                            UERT1160
      END                                                               UERT1170
      SUBROUTINE UGETIO(IOPT,NIN,NOUT)                                  UGET0480
C                                  SPECIFICATIONS FOR ARGUMENTS         UGET0490
      INTEGER            IOPT,NIN,NOUT                                  UGET0500
C                                  SPECIFICATIONS FOR LOCAL VARIABLES   UGET0510
      INTEGER            NIND,NOUTD                                     UGET0520
      DATA               NIND/5/,NOUTD/6/                               UGET0530
C                                  FIRST EXECUTABLE STATEMENT           UGET0540
      IF (IOPT.EQ.3) GO TO 10                                           UGET0550
      IF (IOPT.EQ.2) GO TO 5                                            UGET0560
      IF (IOPT.NE.1) GO TO 9005                                         UGET0570
      NIN = NIND                                                        UGET0580
      NOUT = NOUTD                                                      UGET0590
      GO TO 9005                                                        UGET0600
    5 NIND = NIN                                                        UGET0610
      GO TO 9005                                                        UGET0620
   10 NOUTD = NOUT                                                      UGET0630
 9005 RETURN                                                            UGET0640
      END                                                               UGET0650
      SUBROUTINE GGUBS (DSEED,NR,R)                                     GGUS0390
C                                  SPECIFICATIONS FOR ARGUMENTS         GGUS0400
```

```
      INTEGER            NR                                                 GGUS0410
      REAL               R(NR)                                              GGUS0420
      DOUBLE PRECISION   DSEED                                              GGUS0430
C                                   SPECIFICATIONS FOR LOCAL VARIABLES     GGUS0440
      INTEGER            I                                                  GGUS0450
      DOUBLE PRECISION   D2P31M,D2P31                                       GGUS0460
C                                   D2P31M=(2**31) - 1                      GGUS0470
C                                   D2P31 =(2**31)(OR AN ADJUSTED VALUE)   GGUS0480
      DATA               D2P31M/2147483647.D0/                              GGUS0490
      DATA               D2P31/2147483648.D0/                               GGUS0500
C                                   FIRST EXECUTABLE STATEMENT             GGUS0510
      DO 5 I=1,NR                                                           GGUS0520
         DSEED = DMOD(16807.D0*DSEED,D2P31M)                                GGUS0530
    5 R(I) = DSEED / D2P31                                                  GGUS0540
      RETURN                                                                GGUS0550
      END                                                                   GGUS0560
      SUBROUTINE MCNRIS (P,Y,IER)                                           MCRS0410
C                                   SPECIFICATIONS FOR ARGUMENTS           MCRS0420
      REAL               P,Y                                                MCRS0430
      INTEGER            IER                                                MCRS0440
C                                   SPECIFICATIONS FOR LOCAL VARIABLES     MCRS0450
      REAL               EPS,G0,G1,G2,G3,H0,H1,H2,A,W,WI,SN,SD              MCRS0460
      REAL               SIGMA,SQRT2,X,XINF                                 MCRS0470
      DATA               XINF/Z7FFFFFFF/                                    MCRS0480
      DATA               SQRT2/1.414214/                                    MCRS0490
      DATA               EPS/Z3C100000/                                     MCRS0500
      DATA               G0/.1851159E-3/,G1/-.2028152E-2/                   MCRS0510
      DATA               G2/-.1498384/,G3/.1078639E-1/                      MCRS0520
      DATA               H0/.9952975E-1/,H1/.5211733/                       MCRS0530
      DATA               H2/-.6888301E-1/                                   MCRS0540
C                                   FIRST EXECUTABLE STATEMENT             MCRS0550
      IER = 0                                                               MCRS0560
      IF (P .GT. 0.0 .AND. P .LT. 1.0) GO TO 5                              MCRS0570
      IER = 129                                                             MCRS0580
      SIGMA = SIGN(1.0,P)                                                   MCRS0590
      Y = SIGMA * XINF                                                      MCRS0600
      GO TO 9000                                                            MCRS0610
    5 IF(P.LE.EPS) GO TO 10                                                 MCRS0620
      X = 1.0 -(P + P)                                                      MCRS0630
      CALL MERFI (X,Y,IER)                                                  MCRS0640
      Y = -SQRT2 * Y                                                        MCRS0650
      GO TO 9005                                                            MCRS0660
C                                   P TOO SMALL, COMPUTE Y DIRECTLY        MCRS0670
   10 A = P+P                                                               MCRS0680
      W = SQRT(-ALOG(A+(A-A*A)))                                            MCRS0690
C                                   USE A RATIONAL FUNCTION IN 1./W        MCRS0700
      WI = 1./W                                                             MCRS0710
      SN = ((G3*WI+G2)*WI+G1)*WI                                            MCRS0720
```

```
      SD = ((WI+H2)*WI+H1)*WI+H0                                        MCRS0730
      Y = W + W*(GC+SN/SD)                                              MCRS0740
      Y = -Y*SQRT2                                                      MCRS0750
      GO TO 9005                                                        MCRS0760
 9000 CONTINUE                                                          MCRS0770
      CALL UERTST(IER,6HMDNRIS)                                         MCRS0780
 9005 RETURN                                                            MCRS0790
      END                                                               MCRS0800
      SUBROUTINE MERFI (P,Y,IER)                                        MERI0390
C                                  SPECIFICATIONS FOR ARGUMENTS         MERI0400
      REAL               P,Y                                            MERI0410
      INTEGER            IER                                            MERI0420
C                                  SPECIFICATIONS FOR LOCAL VARIABLES   MERI0430
      REAL               A,B,X,Z,W,WI,SN,SD,F,Z2,RINFM,A1,A2,A3,B0,B1,  MERI0440
     *                   B2,B3,C0,C1,C2,C3,D0,D1,D2,E0,E1,E2,E3,F0,F1,  MERI0450
     *                   F2,G0,G1,G2,G3,HC,H1,H2,SIGMA                  MERI0460
      DATA               A1/-.5751703/,A2/-1.896513/,A3/-.5496261E-1/   MERI0470
      DATA               B0/-.1137730/,B1/-3.293474/,B2/-2.374996/      MERI0480
      DATA               B3/-1.187515/                                  MERI0490
      DATA               C0/-.1146666/,C1/-.1314774/,C2/-.2368201/      MERI0500
      DATA               C3/.5073975E-1/                                MERI0510
      DATA               D0/-44.27977/,D1/21.98546/,D2/-7.586103/       MERI0520
      DATA               E0/-.5668422E-1/,E1/.3937021/,E2/-.3166501/    MERI0530
      DATA               E3/.6208963E-1/                                MERI0540
      DATA               F0/-6.266786/,F1/4.666263/,F2/-2.962883/       MERI0550
      DATA               G0/.1851159E-3/,G1/-.2028152E-2/               MERI0560
      DATA               G2/-.1498384/,G3/.1078639E-1/                  MERI0570
      DATA               H0/.9952975E-1/,H1/.5211733/                   MERI0580
      DATA               H2/-.6888301E-1/                               MERI0590
      DATA               RINFM/Z7FFFFFFF/                               MERI0600
C                                  FIRST EXECUTABLE STATEMENT           MERI0610
      IER = 0                                                           MERI0620
      X = P                                                             MERI0630
      SIGMA = SIGN(1.0,X)                                               MERI0640
C                                  TEST FOR INVALIC ARGUMENT            MERI0650
      IF (.NOT.(X.GT.-1. .AND. X.LT.1.)) GO TO 30                       MERI0660
      Z = ABS(X)                                                        MERI0670
      IF (Z.LE. .85) GC TO 20                                           MERI0680
      A = 1.-Z                                                          MERI0690
      B = Z                                                             MERI0700
C                                  REDUCEC ARGUMENT IS IN (.85,1.),     MERI0710
C                                     OBTAIN THE TRANSFORMED VARIABLE   MERI0720
    5 W = SCRT(-ALCG(A+A*B))                                            MERI0730
      IF (W.LT.2.5) GC TC 15                                            MERI0740
      IF (W.LT.4.) GO TO 10                                             MERI0750
C                                  W GREATER THAN 4., APPROX. F BY A    MERI0760
C                                     RATIONAL FUNCTION IN 1./W         MERI0770
      WI = 1./W                                                         MERI0780
```

```
      SN = ((G3*WI+G2)*WI+G1)*WI                                        MERI0790
      SD = ((WI+H2)*WI+H1)*WI+H0                                        MERI0800
      F = W + W*(G0+SN/SD)                                              MERI0810
      GO TO 25                                                          MERI0820
C                                  W BETWEEN 2.5 AND 4., APPROX. F      MERI0830
C                                     BY A RATIONAL FUNCTION IN W       MERI0840
   10 SN = ((E3*W+E2)*W+E1)*W                                           MERI0850
      SD = ((W+F2)*W+F1)*W+F0                                           MERI0860
      F = W + W*(E0+SN/SD)                                              MERI0870
      GO TO 25                                                          MERI0880
C                                  W BETWEEN 1.13222 AND 2.5, APPROX.   MERI0890
C                                     F BY A RATIONAL FUNCTION IN W     MERI0900
   15 SN = ((C3*W+C2)*W+C1)*W                                           MERI0910
      SD = ((W+D2)*W+D1)*W+D0                                           MERI0920
      F = W + W*(C0+SN/SD)                                              MERI0930
      GO TO 25                                                          MERI0940
C                                  Z BETWEEN 0. AND .85, APPROX. F      MERI0950
C                                     BY A RATIONAL FUNCTION IN Z       MERI0960
   20 Z2 = Z*Z                                                          MERI0970
      F = Z+Z*(B0+A1*Z2/(B1+Z2+A2/(B2+Z2+A3/(B3+Z2))))                  MERI0980
C                                  FORM THE SOLUTION BY MULT. F BY      MERI0990
C                                     THE PROPER SIGN                   MERI1000
   25 Y = SIGMA*F                                                       MERI1010
      IER = 0                                                           MERI1020
      GO TO 9005                                                        MERI1030
C                                  ERROR EXIT. SET SOLUTION TO PLUS     MERI1040
C                                     (OR MINUS) INFINITY               MERI1050
   30 IER = 129                                                         MERI1060
      Y = SIGMA * RINFM                                                 MERI1070
 9000 CONTINUE                                                          MERI1080
      CALL UERTST(IER,6HMERFI )                                         MERI1090
 9005 RETURN                                                            MERI1100
      END                                                               MERI1110
```

APPENDIX B: FORTRAN Survey Analysis Program

```
C      ************************************************************
C      *                                                          *
C      *     THIS PROGRAM CALCULATES AN ITERVAL SCALE FOR ORDINAL *
C      *     DATA TAKEN FROM TWENTY JUDGES RANKING FIVE INSTANCES *
C      *                                                          *
C      ************************************************************
       REAL A(5),B(5,5),C(5,5),Z(5,5),SZ(5),D(5)
       INTEGER MN(5)
       READ (5,100) K
       DO 11 I=1,K
           D(I)=0.0
           DO 10 J=1,K
               B(I,J)=0.0
   10      CONTINUE
   11  CONTINUE
       READ (5,100) L
       DO 30 M=1,L
  100  FORMAT(I5)
           READ(5,101) (A(I),I=1,K)
  101      FORMAT(5F4.1)
           DO 23 I=1,K
               D(I)=D(I)+A(I)
               IF(A(I).EQ.0.0) GO TO 23
               DO 22 J=1,K
                   IF(J.EQ.I) GO TO 22
                   IF(A(J).EQ.0.0) GC TO 22
                   IF(A(I).EQ.A(J)) GO TO 21
                   IF(A(I).LT.A(J)) GO TC 20
                   B(J,I)=B(J,I)+1.0
                   GO TO 22
   20              B(I,J)=B(I,J)+1.0
                   GO TO 22
   21              B(I,J)=B(I,J)+0.5
                   B(J,I)=B(J,I)+0.5
   22          CONTINUE
   23      CONTINUE
   30  CONTINUE
       WRITE(6,201)
 201   FORMAT(1X,'F(I,J) MATRIX')
       DO 35 I=1,K
           WRITE(6,199) (B(I,J),J=1,K)
 199       FORMAT(12X,5(F6.1,2X))
 35    CONTINUE
       WRITE(6,202)
 202   FORMAT(///,1X,'P(I,J) MATRIX')
       DO 42 I=1,K
           DO 41 J=1,K
               IF(I.EQ.J) GO TO 40
```

```
            C(I,J)=B(I,J)/(B(I,J)+B(J,I))
            GO TO 41
 40         C(I,J)=C.50
 41      CONTINUE
         WRITE(6,200) (C(I,J),J=1,K)
 20C     FORMAT(12X,5(F6.2,2X))
 42   CONTINUE
      WRITE(6,203)
203   FORMAT(///,1X,'Z(I,J) MATRIX')
      DO 52 I=1,K
         DO 51 J=1,K
            IF (C(I,J).GT.0.98.OR.C(I,J).LT.0.02) GO TO 50
            CALL MDNRIS(C(I,J),Z(I,J),IER)
            GO TO 51
 50         Z(I,J)=1000.
 51      CONTINUE
         WRITE(6,200) (Z(I,J),J=1,K)
 52   CONTINUE
      WRITE(6,204)
204   FORMAT(////////,16X,'CBJECTIVE FUNCTION COEFFICIENTS')
      WRITE(6,205)
205   FORMAT('+',15X,'________________________________',///)
      WRITE(6,206)
206   FORMAT(5X,'TANKS',6X,'AMTRACKS',5X,'RADIOS',6X,'TRUCKS',
     *5X,'HOWITZERS')
      WRITE(6,207)
207   FORMAT('+',3X,'_______',5X,'________',5X,'______',6X,'______',
     *5X,'_________',/)
      DO 63 I=1,K
         MN(I)=0
         DO 61 J=1,K
            IF(Z(I,J).EQ.1000.) GO TO 60
            SZ(I)=SZ(I)+Z(I,J)
            GO TO 61
 60         MN(I)=2
            WRITE(6,220) I
220         FORMAT(5X,'ROW',I4,' NCT CCMPLETE')
 61      CONTINUE
         IF(MN(I).GT.1) GO TO 63
         SZ(I)=SZ(I)/K
 63   CONTINUE
      DO 88 I=1,K
         SZ(I)=SZ(I)+1.1520
 88   CONTINUE
         WRITE(6,225) SZ(1),SZ(2),SZ(3),SZ(4),SZ(5)
225      FORMAT(1X,5(F10.4,2X))
      RETURN
      END
```

```
      SUBROUTINE MDNRIS (P,Y,IER)                                       MDRS0410
C                                  SPECIFICATIONS FOR ARGUMENTS         MDRS0420
      REAL               P,Y                                            MDRS0430
      INTEGER            IER                                            MDRS0440
C                                  SPECIFICATIONS FOR LOCAL VARIABLES   MDRS0450
      REAL               EPS,G0,G1,G2,G3,H0,H1,H2,A,W,WI,SN,SD          MDRS0460
      REAL               SIGMA,SQRT2,X,XINF                             MDRS0470
      DATA               XINF/Z7FFFFFFF/                                MDRS0480
      DATA               SQRT2/1.414214/                                MDRS0490
      DATA               EPS/Z3C100000/                                 MDRS0500
      DATA               G0/.1851159E-3/,G1/-.2028152E-2/               MDRS0510
      DATA               G2/-.1498384/,G3/.1078639E-1/                  MDRS0520
      DATA               H0/.9952975E-1/,H1/.5211733/                   MDRS0530
      DATA               H2/-.6888301E-1/                               MDRS0540
C                                  FIRST EXECUTABLE STATEMENT           MDRS0550
      IER = 0                                                           MDRS0560
      IF (P .GT. 0.0 .AND. P .LT. 1.0) GO TO 5                          MDRS0570
      IER = 129                                                         MDRS0580
      SIGMA = SIGN(1.0,P)                                               MDRS0590
      Y = SIGMA * XINF                                                  MDRS0600
      GO TO 9000                                                        MDRS0610
    5 IF(P.LE.EPS) GO TO 10                                             MDRS0620
      X = 1.0 -(P + P)                                                  MDRS0630
      CALL MERFI (X,Y,IER)                                              MDRS0640
      Y = -SQRT2 * Y                                                    MDRS0650
      GO TO 9005                                                        MDRS0660
C                                  P TOO SMALL, COMPUTE Y DIRECTLY      MDRS0670
   10 A = P+P                                                           MDRS0680
      W = SQRT(-ALOG(A+(A-A*A)))                                        MDRS0690
C                                  USE A RATIONAL FUNCTION IN 1./W      MDRS0700
      WI = 1./W                                                         MDRS0710
      SN = ((G3*WI+G2)*WI+G1)*WI                                        MDRS0720
      SD = ((WI+H2)*WI+H1)*WI+H0                                        MDRS0730
      Y = W + W*(G0+SN/SD)                                              MDRS0740
      Y = -Y*SQRT2                                                      MDRS0750
      GO TO 9005                                                        MDRS0760
 9000 CONTINUE                                                          MDRS0770
      CALL UERTST(IER,6HMDNRIS)                                         MDRS0780
 9005 RETURN                                                            MDRS0790
      END                                                               MDRS0800
      SUBROUTINE MERFI (P,Y,IER)                                        MERI0390
C                                  SPECIFICATIONS FOR ARGUMENTS         MERI0400
      REAL               P,Y                                            MERI0410
      INTEGER            IER                                            MERI0420
C                                  SPECIFICATIONS FOR LOCAL VARIABLES   MERI0430
      REAL               A,B,X,Z,W,WI,SN,SD,F,Z2,RINFM,A1,A2,A3,B0,B1,  MERI0440
     *                   B2,B3,C0,C1,C2,C3,D0,D1,D2,E0,E1,E2,E3,F0,F1,  MERI0450
     *                   F2,G0,G1,G2,G3,H0,H1,H2,SIGMA                  MERI0460
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      DATA              A1/-.5751703/,A2/-1.896513/,A3/-.5496261E-1/    MERI0470
      DATA              B0/-.1137730/,B1/-3.293474/,B2/-2.374996/       MERI0480
      DATA              B3/-1.187515/                                   MERI0490
      DATA              C0/-.1146666/,C1/-.1314774/,C2/-.2368201/       MERI0500
      DATA              C3/.5073975E-1/                                 MERI0510
      DATA              D0/-44.27977/,D1/21.98546/,D2/-7.586103/        MERI0520
      DATA              E0/-.5668422E-1/,E1/.3937021/,E2/-.3166501/     MERI0530
      DATA              E3/.6208963E-1/                                 MERI0540
      DATA              F0/-6.266786/,F1/4.666263/,F2/-2.962883/        MERI0550
      DATA              G0/.1851159E-3/,G1/-.2028152E-2/                MERI0560
      DATA              G2/-.1498384/,G3/.1078639E-1/                   MERI0570
      DATA              H0/.9952975E-1/,H1/.5211733/                    MERI0580
      DATA              H2/-.6888301E-1/                                MERI0590
      DATA              RINFM/Z7FFFFFFF/                                MERI0600
C                                  FIRST EXECUTABLE STATEMENT           MERI0610
      IER = 0                                                           MERI0620
      X = P                                                             MERI0630
      SIGMA = SIGN(1.0,X)                                               MERI0640
C                                  TEST FCR INVALIC ARGUMENT            MERI0650
      IF (.NOT.(X.GT.-1. .AND. X.LT.1.)) GO TO 30                       MERI0660
      Z = ABS(X)                                                        MERI0670
      IF (Z.LE. .85) GO TO 20                                           MERI0680
      A = 1.-Z                                                          MERI0690
      B = Z                                                             MERI0700
C                                  RECUCEC ARGUMENT IS IN (.85,1.),     MERI0710
C                                     OBTAIN THE TRANSFORMED VARIABLE   MERI0720
    5 W = SQRT(-ALCG(A+A*B))                                            MERI0730
      IF (W.LT.2.5) GO TO 15                                            MERI0740
      IF (W.LT.4.) GO TO 10                                             MERI0750
C                                  W GREATER THAN 4., APPROX. F BY A    MERI0760
C                                     RATIONAL FUNCTION IN 1./W         MERI0770
      WI = 1./W                                                         MERI0780
      SN = ((G3*WI+G2)*WI+G1)*WI                                        MERI0790
      SD = ((WI+H2)*WI+H1)*WI+H0                                        MERI0800
      F = W + W*(GC+SN/SD)                                              MERI0810
      GO TO 25                                                          MERI0820
C                                  W BETWEEN 2.5 AND 4., APPROX. F      MERI0830
C                                     BY A RATIONAL FUNCTION IN W       MERI0840
   10 SN = ((E3*W+E2)*W+E1)*W                                           MERI0850
      SD = ((W+F2)*W+F1)*W+F0                                           MERI0860
      F = W + W*(E0+SN/SD)                                              MERI0870
      GO TC 25                                                          MERI0880
C                                  W BETWEEN 1.13222 AND 2.5, APPROX.   MERI0890
C                                     F BY A RATIONAL FUNCTION IN W     MERI0900
   15 SN = ((C3*W+C2)*W+C1)*W                                           MERI0910
      SD = ((W+D2)*W+C1)*W+D0                                           MERI0920
      F = W + W*(CC+SN/SD)                                              MERI0930
      GO TC 25                                                          MERI0940
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C                                        Z BETWEEN 0. AND .85, APPROX. F     MERI0950
C                                           BY A RATIONAL FUNCTION IN Z      MERI0960
   20 Z2 = Z*Z                                                               MERI0970
      F = Z+Z*(B0+A1*Z2/(B1+Z2+A2/(B2+Z2+A3/(B3+Z2))))                       MERI0980
C                                        FORM THE SOLUTION BY MULT. F BY     MERI0990
C                                           THE PROPER SIGN                  MERI1000
   25 Y = SIGMA*F                                                            MERI1010
      IER = 0                                                                MERI1020
      GO TO 9005                                                             MERI1030
C                                        ERROR EXIT. SET SOLUTION TO PLUS    MERI1040
C                                           (OR MINUS) INFINITY              MERI1050
   30 IER = 129                                                              MERI1060
      Y = SIGMA * RINFM                                                      MERI1070
 9000 CONTINUE                                                               MERI1080
      CALL UERTST(IER,6HMERFI )                                              MERI1090
 9005 RETURN                                                                 MERI1100
      END                                                                    MERI1110
      SUBROUTINE UERTST (IER,NAME)                                           UERT0500
C                                        SPECIFICATIONS FOR ARGUMENTS        UERT0510
      INTEGER              IER                                               UERT0520
      INTEGER*2            NAME(3)                                           UERT0530
C                                        SPECIFICATIONS FOR LOCAL VARIABLES  UERT0540
      INTEGER*2            NAMSET(3),NAMEQ(3)                                UERT0550
      DATA                 NAMSET/2HUE,2HRS,2HET/                            UERT0560
      DATA                 NAMEQ/2H  ,2H  ,2H  /                             UERT0570
C                                        FIRST EXECUTABLE STATEMENT          UERT0580
      DATA                 LEVEL/4/,IEQDF/0/,IEQ/1H=/                        UERT0590
      IF (IER.GT.999) GO TO 25                                               UERT0600
      IF (IER.LT.-32) GO TO 55                                               UERT0610
      IF (IER.LE.128) GO TO 5                                                UERT0620
      IF (LEVEL.LT.1) GO TO 30                                               UERT0630
C                                        PRINT TERMINAL MESSAGE              UERT0640
      CALL UGETIO(1,NIN,IOUNIT)                                              UERT0650
      IF (IEQDF.EQ.1) WRITE(IOUNIT,35) IER,NAMEQ,IEQ,NAME                    UERT0660
      IF (IEQDF.EQ.0) WRITE(IOUNIT,35) IER,NAME                              UERT0670
      GO TO 30                                                               UERT0680
    5 IF (IER.LE.64) GO TO 10                                                UERT0690
      IF (LEVEL.LT.2) GO TO 30                                               UERT0700
C                                        PRINT WARNING WITH FIX MESSAGE      UERT0710
      CALL UGETIO(1,NIN,IOUNIT)                                              UERT0720
      IF (IEQDF.EQ.1) WRITE(IOUNIT,40) IER,NAMEQ,IEQ,NAME                    UERT0730
      IF (IEQDF.EQ.0) WRITE(IOUNIT,40) IER,NAME                              UERT0740
      GO TO 30                                                               UERT0750
   10 IF (IER.LE.32) GO TO 15                                                UERT0760
C                                        PRINT WARNING MESSAGE               UERT0770
      IF (LEVEL.LT.3) GO TO 30                                               UERT0780
      CALL UGETIO(1,NIN,IOUNIT)                                              UERT0790
      IF (IEQDF.EQ.1) WRITE(IOUNIT,45) IER,NAMEQ,IEQ,NAME                    UERT0800
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      IF (IEQDF.EQ.0) WRITE(IOUNIT,45) IER,NAME                         UERT0810
      GO TO 30                                                          UERT0820
   15 CONTINUE                                                          UERT0830
C                                  CHECK FOR UERSET CALL                UERT0840
      DO 20 I=1,3                                                       UERT0850
         IF (NAME(I).NE.NAMSET(I)) GO TO 25                             UERT0860
   20 CONTINUE                                                          UERT0870
      LEVOLD = LEVEL                                                    UERT0880
      LEVEL = IER                                                       UERT0890
      IER = LEVOLD                                                      UERT0900
      IF (LEVEL.LT.0) LEVEL = 4                                         UERT0910
      IF (LEVEL.GT.4) LEVEL = 4                                         UERT0920
      GO TO 30                                                          UERT0930
   25 CONTINUE                                                          UERT0940
      IF (LEVEL.LT.4) GO TO 30                                          UERT0950
C                                  PRINT NON-DEFINED MESSAGE            UERT0960
      CALL UGETIO(1,NIN,IOUNIT)                                         UERT0970
      IF (IEQDF.EQ.1) WRITE(IOUNIT,50) IER,NAMEQ,IEQ,NAME               UERT0980
      IF (IEQDF.EQ.0) WRITE(IOUNIT,50) IER,NAME                         UERT0990
   30 IEQDF = 0                                                         UERT1000
      RETURN                                                            UERT1010
   35 FORMAT(19H *** TERMINAL ERROR,10X,7H(IER = ,I3,                   UERT1020
     1       20H) FROM IMSL ROUTINE ,3A2,A1,3A2)                        UERT1030
   40 FORMAT(36H *** WARNING WITH FIX ERROR  (IER = ,I3,                UERT1040
     1       20H) FROM IMSL ROUTINE ,3A2,A1,3A2)                        UERT1050
   45 FORMAT(18H *** WARNING ERROR,11X,7H(IER = ,I3,                    UERT1060
     1       20H) FROM IMSL ROUTINE ,3A2,A1,3A2)                        UERT1070
   50 FORMAT(20H *** UNDEFINED ERROR,9X,7H(IER = ,I5,                   UERT1080
     1       20H) FROM IMSL ROUTINE ,3A2,A1,3A2)                        UERT1090
C                                  SAVE P FOR P = R CASE                UERT1100
C                                    P IS THE PAGE NAME                 UERT1110
C                                    R IS THE ROUTINE NAME              UERT1120
   55 IEQDF = 1                                                         UERT1130
      DO 60 I=1,3                                                       UERT1140
   60 NAMEQ(I) = NAME(I)                                                UERT1150
   65 RETURN                                                            UERT1160
      END                                                               UERT1170
      SUBROUTINE UGETIO(IOPT,NIN,NOUT)                                  UGET0480
C                                  SPECIFICATIONS FOR ARGUMENTS         UGET0490
      INTEGER            IOPT,NIN,NOUT                                  UGET0500
C                                  SPECIFICATIONS FOR LOCAL VARIABLES   UGET0510
      INTEGER            NIND,NOUTD                                     UGET0520
      DATA               NIND/5/,NOUTD/6/                               UGET0530
C                                  FIRST EXECUTABLE STATEMENT           UGET0540
      IF (IOPT.EQ.3) GO TO 10                                           UGET0550
      IF (IOPT.EQ.2) GO TO 5                                            UGET0560
      IF (IOPT.NE.1) GO TO 9005                                         UGET0570
      NIN = NIND                                                        UGET0580
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      NOUT = NOUTC                                                      UGET0590
      GO TO 9005                                                        UGET0600
    5 NIND = NIN                                                        UGET0610
      GO TO 9005                                                        UGET0620
   10 NOUTD = NOUT                                                      UGET0630
 9005 RETURN                                                            UGET0640
      END                                                               UGET0650
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LIST OF REFERENCES

1. U.S. Marine Corps, MIMMS Introduction Manual, Marine Corps Order P4790.1, Washington, D.C.: Headquarters Marine Corps, 1976.

2. U.S. Marine Corps, MIMMS Field Procedures Manual, Marine Corps Order P4790.2A, Washington, D.C.: Headquarters Marine Corps, January 1979.

3. U.S. Marine Corps, MIMMS Depot Procedures Manual, Marine Corps Order P4790.3, Washington, D.C.: Headquarters Marine Corps, February 1974.

4. U.S. Marine Corps, MIMMS Depot Users Manual, Marine Corps Order P4790.6, Washington, D.C.: Headquarters Marine Corps, 1977.

5. Blondin, Peter, Practical Comptrollership Course, Module A, Naval Postgraduate School, 1980.

6. U.S. Department of Defense, Standardization of Work Measurement, *Department of Defense* 5010.15.1-M, Washington, D.C.: 1974.

7. Defense Productivity Program Office, Computer Aided Time Standards, Falls Church, Virginia: Department of Defense, 1980.

8. U.S. Marine Corps, MIMMS Headquarters Procedures Manual, Marine Corps Order P4790.4, Washington, D.C.: Headquarters Marine Corps, 1982.

9. Batchelder, C.A., Boren, H.E., Campbell, H.G., Dei Rossi, J.A., Large, J.P., An Introduction to Equipment Cost Estimating, Memorandum RM-6103-SA, a document prepared by the Rand Corporation for the Office of the Assistant Secretary of Defense, December 1969.

10. U.S. Marine Corps, Nonconsumable Item Program, Marine Corps Order P4410.22A, Washington, D.C.: Headquarters Marine Corps, March 1978.

11. Torgerson, Warren S., Theory and Methods of Scaling, Wiley, 1958.

12. Hillier, Fredrick S., Lieberman, Gerald J., Introduction to Operations Research, Holden-Day, Inc., 1980.

13. U.S. Marine Corps, Depot Level Maintenance Program, Marine Corps Logistics Base, Albany, Georgia, March 1981.

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